Total Maximum Daily Load Development

Mill Creek Bacteria (*E. coli*) Impairment

Page County, Virginia

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Located in Page County, Virginia, the Mill Creek (VAV-B38R, 8,221 acres) watershed is located southwest of Luray. Mill Creek is a tributary of the South Fork of the Shenandoah River (USGS Hydrologic Unit 02070005). The Shenandoah River flows into the Potomac River. The Potomac River discharges into the Chesapeake Bay.

1.2. Bacteria Impairment

Water quality samples collected in Mill Creek over a period of 11½ years (December 1991 – June 2003) indicated that 51% of the samples violated the instantaneous water quality standard for fecal coliform. The instantaneous freshwater water quality standard for fecal coliform under which the Mill Creek impairment was listed specified that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the frequency of water quality violations, Mill Creek was placed on Virginia's 1998 303(d) list of impaired water bodies for fecal coliform. It has been assessed as not supporting the Recreational Use Support Goal for the 1998 305(b) report. The impairment starts at the headwaters and continues downstream to the confluence with the South Fork Shenandoah River. This includes a total of 6.78 stream miles for Mill Creek.

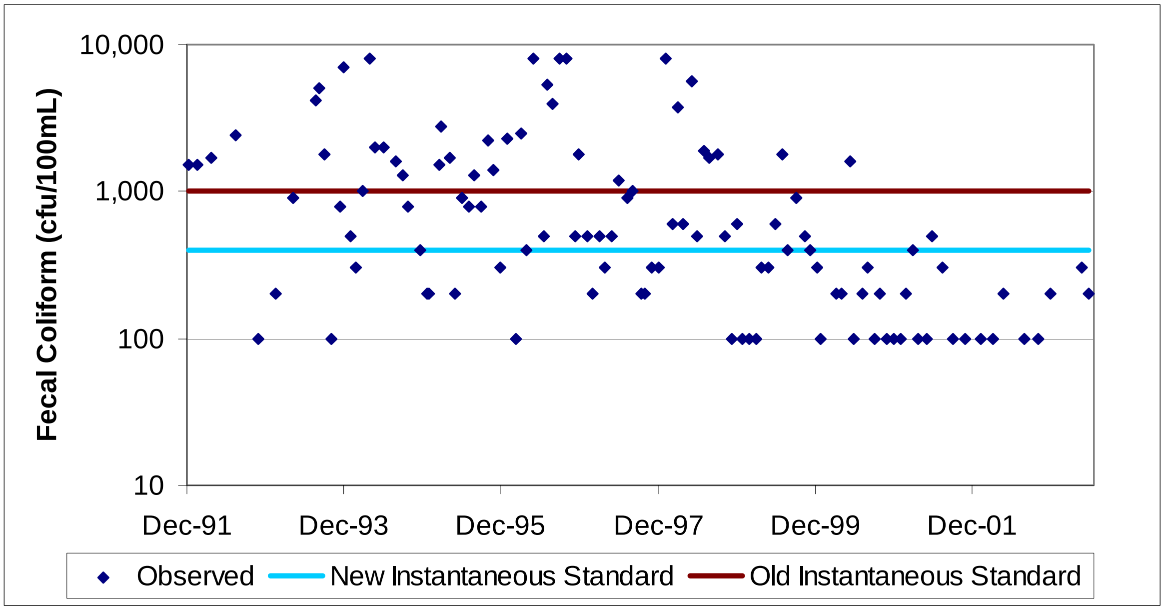

Figure 1-1. VADEQ monitored fecal coliform concentrations in Mill Creek.

In order to remedy the fecal coliform water quality impairment, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample may exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.3. Sources of Bacteria

All of the bacteria load in the Mill Creek watershed originates from nonpoint sources. The nonpoint sources of bacteria are mainly agricultural and include land-applied animal waste and manure deposited on pastures by livestock. A significant bacteria load comes from cattle and wildlife directly depositing feces in streams. Wildlife also contribute to bacteria loadings on forest and other land uses, in accordance with the habitat range for each species. Non-agricultural nonpoint sources of bacteria loadings include sanitary sewer overflows (SSOs), failing septic systems, household straight pipes, and pet waste. The amounts of bacteria produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife behavior and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement, pastures, or streams; the amount of manure storage; and spreading schedules for manure application, were considered on a monthly basis.

1.4. Modeling

The Hydrological Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Mill Creek watershed. To identify localized sources of fecal coliform within the Mill Creek watershed, Mill Creek was divided into 7 sub-watersheds, based primarily on confluences with tributaries.

As no observed flow data was available for the watershed and the neighboring Hawksbill Creek watershed had recently been modeled with HSPF as part of a TMDL study, the calibrated hydrology parameter values from Hawksbill Creek were applied to Mill Creek.

A significant, permanent drop in observed fecal coliform concentrations occurred in the middle of the observed data record, as shown in Figure 1-1.The calibration of the water quality components of HSPF for Mill Creek was, therefore, simulated as two sets of land use and management practices in order to capture the changes that had occurred in the watershed. Observed data were available for the period from December 1991 through 2003. The period of change was during the calendar year 1998. Water quality calibration was performed independently for a period before the change and a period after the change. The first period of calibration ran from December 1991 through 1997 using one set of watershed characteristics. The observed data following the period of change ran from 1999 through 2003. This period was divided into two periods: from 1999 to 2000 – used for the second period of calibration, and from 2001 through 2003 – used for validation with the same set of watershed model parameters used during the second period of calibration. Bacteria inputs to the model from loads both applied to the land surface and deposited directly in stream were distributed monthly by source in an external spreadsheet. A comparison of simulated and observed in-stream fecal coliform concentrations indicated that the model adequately simulated the fate and transport of fecal coliform in the watershed.

1.5. Margin of Safety

A margin of safety (MOS) is included to account for uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For Mill Creek, the MOS was implicitly incorporated into each TMDL by a conservative calibration of the water quality bacteria parameters.

1.6. Existing Conditions

Contributions from various sources within the Mill Creek watershed were represented in HSPF to simulate bacteria loadings for existing conditions. Average annual loads were calculated using meteorological inputs for the same 1990-2002 period used in neighboring Hawksbill Creek. Forty-one percent of the fecal coliform in the mean daily fecal coliform concentration comes from cattle directly depositing in the stream, 52% from upland areas due to runoff, 5% from wildlife directly depositing in the stream, and approximately 2% from straight pipes, sanitary sewer overflows, runoff from impervious areas, and contributions from interflow and groundwater.

For existing conditions in Mill Creek, simulated bacteria concentrations exceeded the calendar-month geometric mean water quality standard 77% of the time, and by larger amounts during low flow periods and the summer. During the summer when stream flow is lower, cattle tend to spend more time in streams, increasing direct fecal coliform deposition to streams when water for dilution is least available.

1.7. TMDL Allocations and Stage 1 Implementation

Based on amounts of bacteria produced in different locations, monthly bacteria loadings to different land use categories were calculated for each sub-watershed for input into the respective models. Bacteria content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, bacteria die-off on land was taken into account, as was the reduction in bacteria available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal bacteria loadings to streams by cattle were calculated for pastures adjacent to streams. Bacteria loadings to streams and land by wildlife were estimated for several species. Bacteria loadings to land from failing septic systems were estimated based on number and age of houses. Bacteria contributions from sanitary sewer overflows and pet waste were also considered.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface and directly deposited in the stream; these reductions are presented in the tables in Section 1.8. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Section 1.8 indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) can be accomplished through implementation of BMPs like filter strips, stream fencing, and off-stream watering. The required reductions from residential source categories can be accomplished through such measures as repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures that will be identified and quantified in the next step in the TMDL process, the development of a TMDL Implementation Plan.

For the TMDL allocation scenarios, a target of zero violations of both the instantaneous and geometric mean water quality standards was used. For the

Stage 1 implementation scenario, reductions were required to achieve a target instantaneous single sample criterion violation rate of no more than 10%.

1.8. Allocation Scenarios for Mill Creek

After calibrating to the existing water quality conditions, different source reduction scenarios were evaluated to identify one or more scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The incremental scenarios modeled to achieve compliance are presented in Table 1-1.

Table 1-1. Allocation scenarios for the Mill Creek watershed.

Scenario Number	% Violation of *E. coli* criterion		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%							
	Geomean	Single Sample	SSO	Straight Pipes	Failing Septic Systems	Livestock DD	Manure on Agriculture PLS	Residential PLS+ILS	Forest PLS	Wildlife DD
Existing Conditions	95%	60%	0	0	0	0	0	0	0	0
Future	89%	57%	0	0	0	0	0	0	0	0
1	89%	57%	100	0	0	0	0	0	0	0
2	83%	56%	100	100	0	0	0	0	0	0
3	83%	56%	100	100	100	0	0	0	0	0
4	39%	9.8%	100	100	100	84	50	50	0	0
5	33%	9.8%	100	100	100	80	80	80	0	0
6	0%	0.02%	100	100	100	100	100	100	0	0
7	0%	0%	100	100	100	100	100	100	40	0

- Stage 1 Scenarios
- TMDL Scenario

In all scenarios considered in Table 1-1, bacteria contributions from sanitary sewer overflows (SSOs) were eliminated because these contributions are covered under an existing out-of-the-watershed permit for the Stanley STP and are being addressed in conjunction with VADEQ. Two additional categories of bacteria contributions also addressed under existing regulations are household straight pipes and failing septic systems, which were eliminated in Scenarios 2 and 3, respectively, and in all succeeding scenarios. The reductions achieved from all of the currently regulated sources through Scenario 3, however, had little impact on reducing the overall percentage of bacteria violations. All following reduction scenarios, therefore, include reductions from the major influence on in-stream concentrations – livestock direct deposit (DD). Scenarios 4 and 5 represent alternative Stage 1 reduction scenarios with single standard criterion violation rates less than 10%. Scenario 6 shows that violations of the single sample criterion cannot be eliminated even with 100% reductions from everything except background wildlife sources. The last scenario – Scenario 7 – was developed to eliminate all violations of both the calendar-month geometric mean and the single sample criteria and requires, in addition to all the previous reductions, a 40% reduction in the direct deposits in land deposited waste from wildlife, whose reductions are exempted under current state guidelines. Because reductions have already been made to all other human-related sources of bacteria, Scenario 7 is the only option as a recommended TMDL scenario.

The required load reductions for the TMDL allocation for wet weather nonpoint sources are listed in Table 1-2 and for direct nonpoint sources in Table 1-3. The concentrations for the calendar-month geometric mean and daily average *E. coli* values are shown in Figure 1-2 for the TMDL allocation (Scenario 7), along with the fresh water bacteria water quality criteria.

Loadings for existing conditions and the TMDL allocation scenario (Scenario 7) are presented for nonpoint sources by land use in Table 1-2 and for direct nonpoint sources in Table 1-3. It is clear that extreme reductions in loads, both from land surfaces and from sources directly depositing in the streams of Mill Creek, are required to meet both the calendar-month geometric mean and single sample criteria for *E. coli*. Direct deposition by livestock in streams is the greatest influence on the *E. coli* concentration in-stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are minimal during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas becomes a major periodic influence on in-stream concentrations. Because these upland loadings are intermittent, they are a minor influence on concentrations that violate the calendar-month geometric mean standard, but they have a major influence on violations of the *E. coli* single sample criterion.

Table 1-2. Annual nonpoint source fecal coliform loads under Existing Conditions and corresponding reductions for TMDL allocation Scenario 7.

Land use Category	Existing Conditions		Allocation Scenario 7	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	113	0.5%	0	100%
Pasture	20,257	96.8%	0	100%
Hay	284	1.4%	0	100%
Residential[a]	154	0.7%	0	100%
Forest	130	0.6%	78	40%
Total	20,937		78	-

[a] Includes loads applied to both High and Low Density Residential

Table 1-3. Annual direct nonpoint source fecal coliform loads under Existing Conditions and corresponding reductions for TMDL allocation Scenario 7.

Source	Existing Condition		Allocation Scenario 7	
	Existing conditions load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
SSOs	0.8	1.2%	0	100%
Straight Pipes	0.7	1.0%	0	100%
Wildlife in Streams	7.1	10.0%	7.1	0%
Livestock in Streams	62.6	87.9%	0	100%
Total	71.3		7.1	-

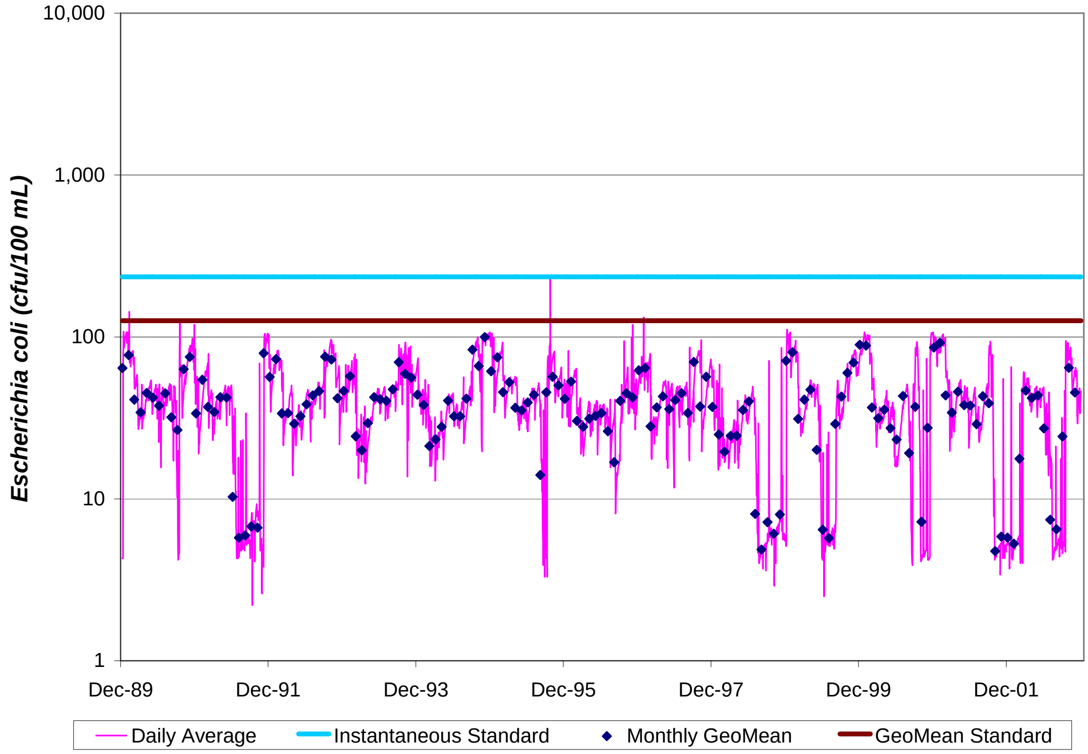

Figure 1-2. The *E. coli* TMDL allocation scenario for Mill Creek (Scenario 7) and applicable Calendar-month Geometric Mean and Instantaneous water quality criteria.

Using Equation [1.1], the TMDL allocation was calculated as shown in Table 1-4.

$$TMDL = \Sigma WLA + \Sigma LA + MOS \qquad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, implicit.

There were no permitted point source discharges of bacteria in the watershed; therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. The

MOS was accounted for through a conservative calibration of water quality (bacteria) parameter values. The LA was then determined as the TMDL-WLA.

Table 1-4. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Mill Creek bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS	TMDL
E. coli	0	8.51×10^{13}	Implicit	8.51×10^{13}

The proposed scenario requires a 100% reduction in bacteria loads from all anthropogenic sources on the land surface, a 100% reduction from livestock direct-deposits, and a 40% reduction from wildlife deposits on upland areas in order to meet the *E. coli* standard. Furthermore, complete elimination of sanitary sewer overflows, household straight pipes, and failing septic systems is required to meet the TMDL goal.

1.9. Stage 1 Implementation

A transitional scenario was identified to establish the first step in the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Stage 1 implementation was developed for a maximum of 10% violation rate of the instantaneous single sample *E. coli* water quality criterion (235 cfu/100 mL), based on daily averages of the simulated concentrations (Scenario 4, Table 1-1). In addition, the Stage 1 scenario was designed without reductions from wildlife.

Two alternative Stage 1 scenarios - Scenarios 4 and 5 - were presented in Table 1-1. The Stage 1 implementation scenarios were developed taking into consideration concerns expressed by the Local Steering Committee about stream fencing being the only alternative. Frequent flooding and fence maintenance were mentioned as potential concerns that might prevent local stakeholder participation in incentive programs that would offset only the installation cost of stream fencing. Both of the Stage 1 alternatives include reductions from other sources as well, but recognize that even the modest Stage 1 goal could not be achieved without as least some reductions from livestock direct deposit. Scenario 4 is the recommended Stage 1 scenario as the additional 4% reduction in direct livestock deposits would offset 30% fewer reductions from all upland land applied sources. Reductions in loads from cropland, residential areas, and wildlife direct deposit in the stream are not required.

Based on the State's monthly or bimonthly monitoring schedules and water quality assessment guidance, achievement of the Stage I Implementation Scenario is expected to result in an assessment of fully supporting. The State's assessment guidance uses a 10.5% violation rate of the instantaneous standard as the criteria for assessing a bacterial impairment.

1.10. Reasonable Assurance of Implementation

1.10.1. Follow-Up Monitoring

The Department of Environmental Quality (VADEQ) will continue monitoring Mill Creek (1BMLC000.40) in accordance with its ambient monitoring programs to evaluate reductions in fecal bacteria counts and also the effectiveness of TMDL implementation in attainment of water quality standards.

1.10.2. Regulatory Framework

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairment on Mill Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.10.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's

Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

1.11. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. On July 12, 2004, members of Virginia Tech's Center for TMDL and Watershed Studies in the Biological Systems Engineering Department, along with the regional VADEQ watershed coordinator and other watershed residents were invited by the Page County Water Quality Advisory Committee to take a watershed tour of Mill Creek in order to acquaint them with local features and concerns in the watershed. Later that afternoon, the first of three meetings of the Mill Creek Local Steering Committee was held at the Page County Court House in Luray, Virginia with 20 stakeholders in attendance. At this meeting, initial bacteria source characterization estimates were presented, together with a discussion of applicable land use and management characteristics of potential nonpoint sources of bacteria, as developed previously by the Local Steering Committee for neighboring Hawksbill Creek. The first public meeting was held on October 20, 2004, also at the Page County Court House in Luray, to inform the stakeholders of the TMDL development process and to receive further feedback on watershed and bacteria source characterization data collected for the Mill Creek watershed. The Local Steering Committee met a second time immediately following the public meeting. Public participation included 27 people for the public meeting and 14 for the Steering Committee meeting. A third meeting of the Mill Creek Local Steering Committee was held on January 27, 2005 to present progress made with model calibration, refinements made to initial bacteria source characterization estimates, and preliminary allocation results from modeling bacteria loads, attended by 20 stakeholders. The final public meeting on March 2, 2005 was also held at the Page County Courthouse in Luray to present the draft TMDL report and to solicit stakeholder comments. Attendance at the final public meeting was 27 people. One comment was received during the following 30-day comment period and was subsequently addressed by DEQ.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Mill Creek (Segment ID VAV-B38R_MLC01A00) was listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of the bacteria standard. The source of the impairment was listed as agricultural nonpoint sources.

The Virginia Department of Environmental Quality (VADEQ) has delineated the impairments on Mill Creek on a stream length of 6.78 miles. The impaired stream segment begins at the Mill Creek headwaters and continues downstream to its confluence with the South Fork of the Shenandoah River. Mill Creek is targeted for TMDL development and completion by 2010.

2.1.3. Watershed Location and Description

A part of the Shenandoah River basin, the Mill Creek watershed (Watershed ID VAV-B38R) is located in Page County, southwest of Luray (Figure 2-1). The watershed is 8,221 acres in size. Mill Creek is mainly an agricultural watershed (about 75%) and is characterized by a rolling valley with the Blue Ridge Mountains to the east and the Appalachian Mountains to the west. Another 19% of the watershed is forested with the remainder in a mix of residential and commercial uses. Mill Creek flows north and discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005), which flows into the Potomac River; the Potomac River discharges into the Chesapeake Bay.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform counts are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state fecal coliform standard for contact recreational uses. As discussed in Section 2.2.2, Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

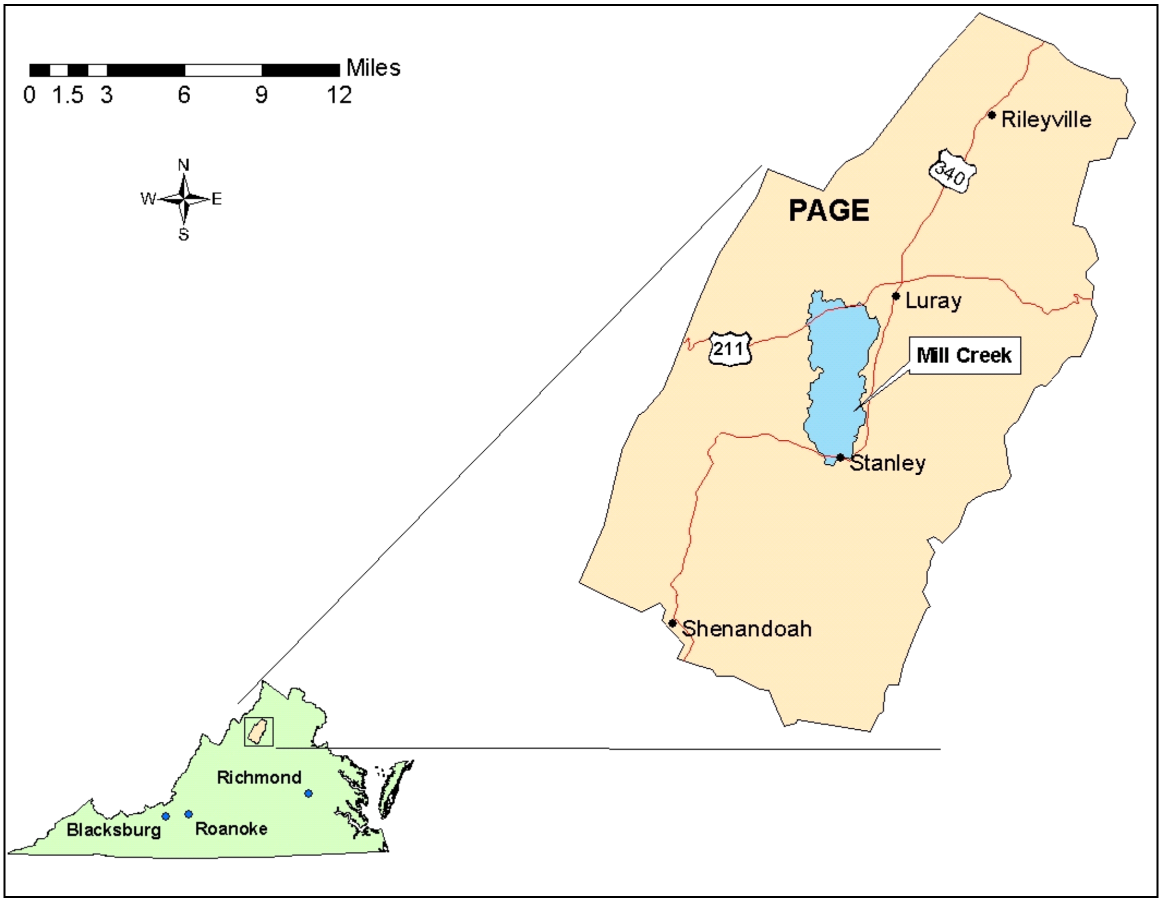

Figure 2-1. Location of Mill Creek watershed.

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish." VGA, 2005.

Mill Creek does not support the recreational (swimming) designated use due to violations of the bacteria criteria.

2.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. Since that date, the *E. coli* standard described below has applied to all freshwater streams in Virginia. Until June 30, 2008, the interim fecal coliform standard will be used for any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (VADEQ, 2000):

Interim Fecal Coliform Standard:

> Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

Escherichia coli Standard:

> *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed an instantaneous single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. The original impairment to Mill Creek was based on violations of an earlier fecal coliform standard that included a numeric single sample maximum limit of 1000 cfu/100 mL. The bacteria TMDL for these impaired segments will be developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output to *E. coli*.

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

The Mill Creek Watershed is located just southwest of the town of Luray, and includes the towns of Stanley and Hamburg. The watershed was divided into 7 sub-watersheds to assist in the characterization of spatially distributed pollutant sources for modeling purposes, as shown in Figure 3.1. The main branch of Mill Creek runs for 7.24 miles from the headwaters until it enters the South Fork of the Shenandoah River. Mill Creek consists of both perennial and intermittent reaches with both having trapezoidal channel cross-sections. Aquifers in this watershed are overlain by limestone (VWCB, 1985). The presence of numerous solution cavities with intensive agricultural use results in a high potential for groundwater pollution (VWCB, 1985).

3.2. Ecoregion

The Mill Creek watershed is located in the Ridge and Valley Level III Ecoregion, and in the Northern Limestone/Dolomite Valleys Level IV Ecoregion. The Ridge and Valley Level III Ecoregion is characterized by its generation from sedimentary rocks, including sandstone, shale, limestone, and dolomite. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land. The Northern Limestone/Dolomite Valleys Level IV ecoregion is characterized by broad, level to undulating, fertile valleys that are extensively farmed, and scattered woodlands on steeper areas. Sinkholes, underground streams, and other karst features have developed on the underlying limestone and dolomite. Streams tend to flow year-round and have gentle slopes. Forests in the southern part of the ecoregion covering Virginia are composed primarily of oak, hickory, and pine (Woods et al., 1999).

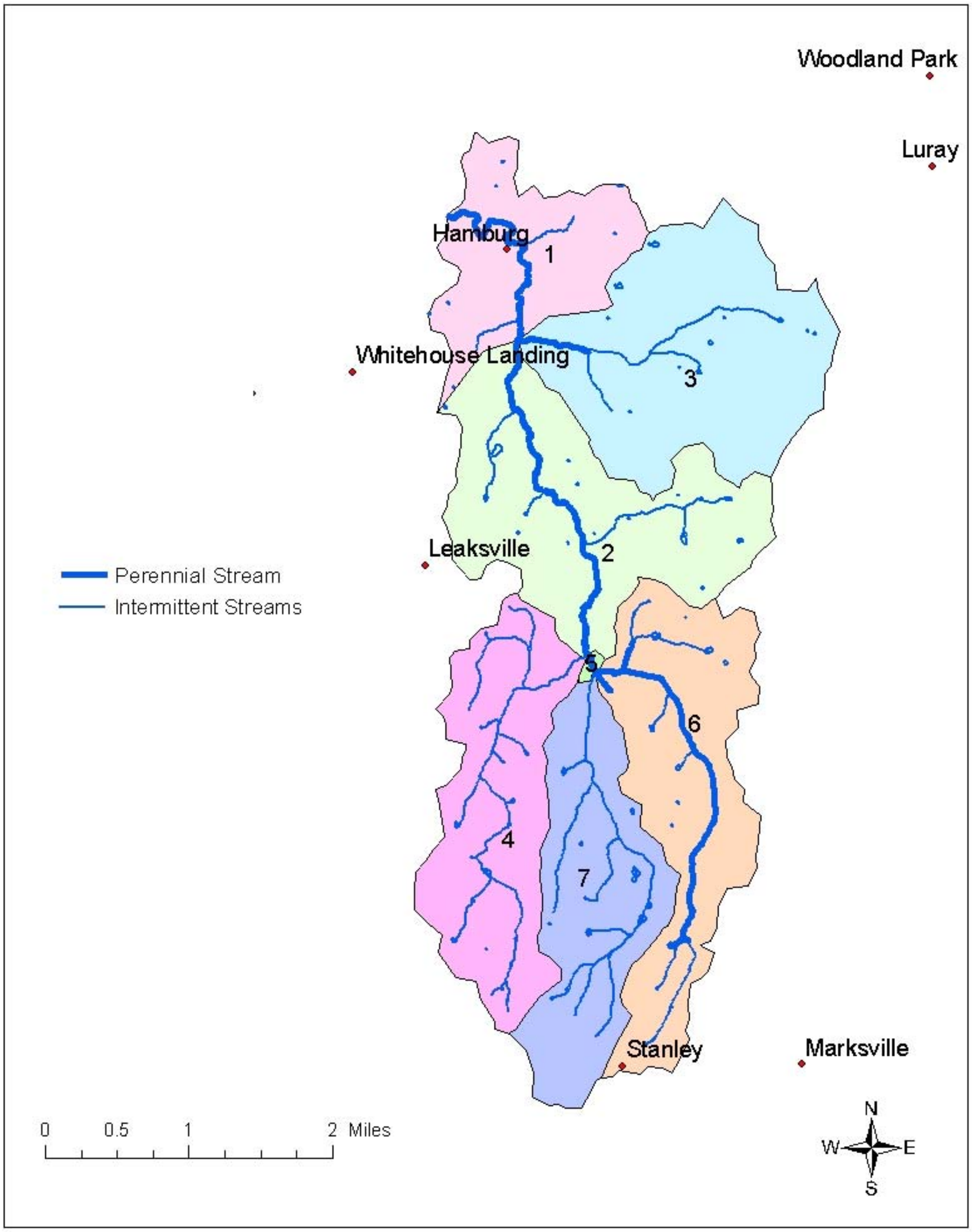

Figure 3-1. Mill Creek Sub-Watersheds.

3.3. Soils and Geology

The predominant soils found in Mill Creek watershed are the Lodi silt loam and Braddock loam soils. Both of these soils are very deep and well drained with clayey subsoil and areas of rock outcrop. In upland areas, each of these soils is underlain by limestone bedrock. These two general soil map units are found on gently sloping to steep topography with medium to rapid surface runoff (USDA-NRCS, 2001).

3.4. Climate

The climate data used in the computer modeling of the watershed were based on the meteorological observations made by the National Weather Service's station in the community of Luray. The Luray weather station is located 6.0 miles northeast of Mill Creek. The Luray climate data set is essentially the same as was used for the Hawksbill Creek TMDL in an adjacent watershed, with the period of record extended through 2003. Average annual precipitation at that station is 40.67 in. with 56% of the precipitation occurring during the crop-growing season (May-October). Average annual snowfall is 24.4 in. with the highest snowfall occurring during January. Average annual daily temperature is 53.5°F. The highest average daily temperature of 73.4°F occurs in July while the lowest average daily temperature of 32.7°F occurs in January (SERCC, 2005).

3.5. Land Use

Pasture is the main land use category in Mill Creek, comprising 70% of the total watershed area, while about 19% of the watershed area is forested and about 5% is in cropland. Residential and urban developments, which cover 6% of the total area, are spread throughout the watershed but are slightly concentrated near the headwaters and the outlet.

3.6. Stream Flow Data

No observed flow data were available for Mill Creek.

3.7. Water Quality Data

Virginia VADEQ began monitoring bacterial water quality in the Mill Creek watershed starting in December 1991 using fecal coliform as the indicator parameter. Sampling and subsequent analysis occurred on a quarterly basis from December 1991 through April 1993, on a monthly basis from July 1993 through July 2001, and every other month from September 2001 through June 2003. From July 2003 through June 2004, monthly samples collected for bacterial source tracking (BST) analysis were additionally analyzed for both fecal coliform and *Escherichia coli* (*E. coli*).

Water quality monitoring data were also available from three stations monitored from September 1998 through December 2001 by the Page County Water Quality Committee and processed by Tom Benzing at James Madison University. These stations (FP-13, FP-13A, and FP-13B) are shown in Figure 3-2.

3.7.1. Historic Data – Fecal Coliform

Virginia VADEQ personnel have monitored pollutant concentrations near the outlet of the Mill Creek watershed at Station No. 1BMLC000.40 for over eleven and a half years (Figure 3-2). The Virginia Department of Conservation and Recreation has assessed this watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 118 water quality samples collected by VADEQ during this monitoring period, 32% exceeded the old single sample maximum fecal coliform standard of 1,000 cfu/100 mL, as shown in Figure 3-3. Consequently, this segment of Mill Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and was included in the 1998 303(d) list (USEPA, 1998a, b).

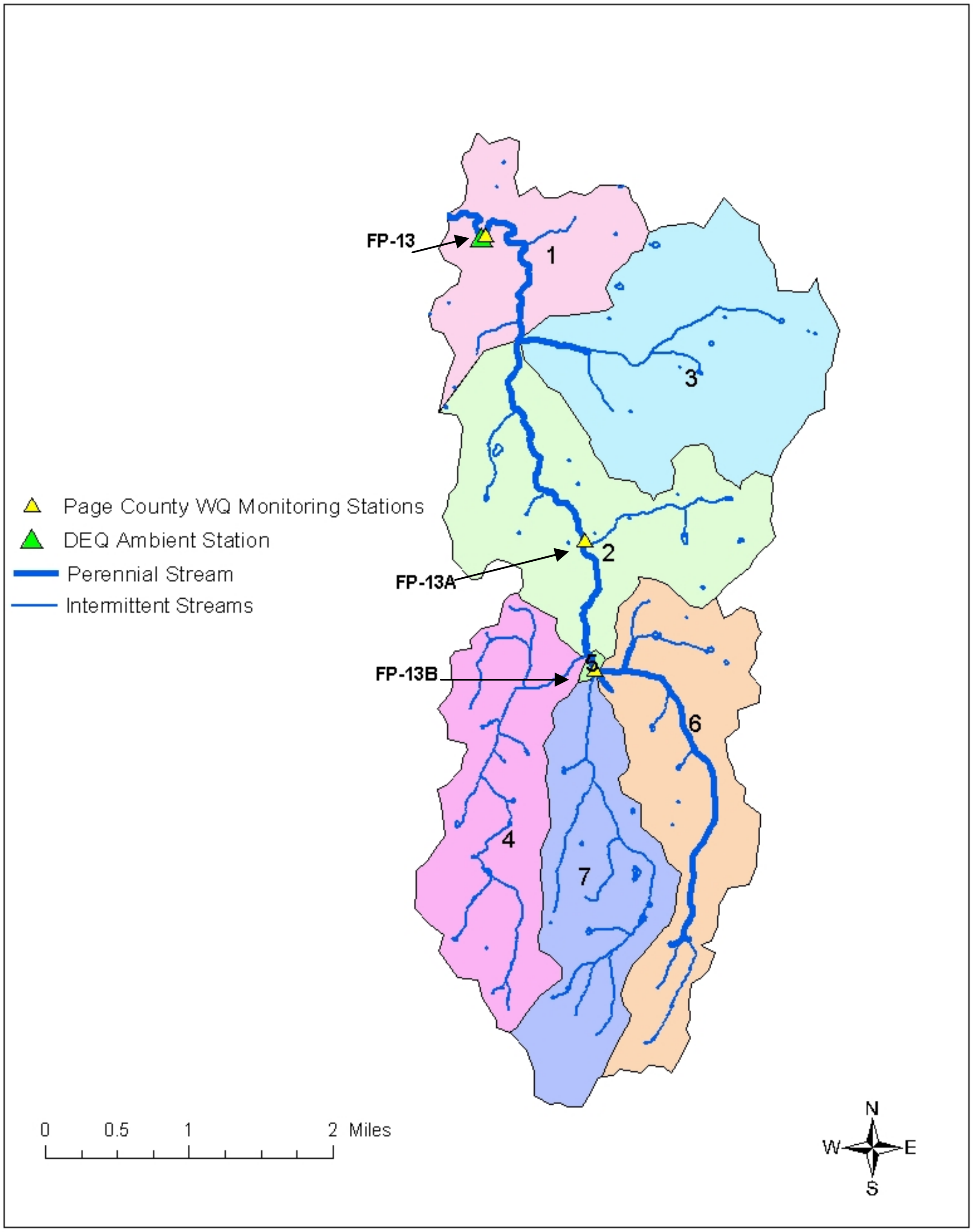

Figure 3-2. Location of VADEQ and volunteer bacteria monitoring stations in the Mill Creek watershed.

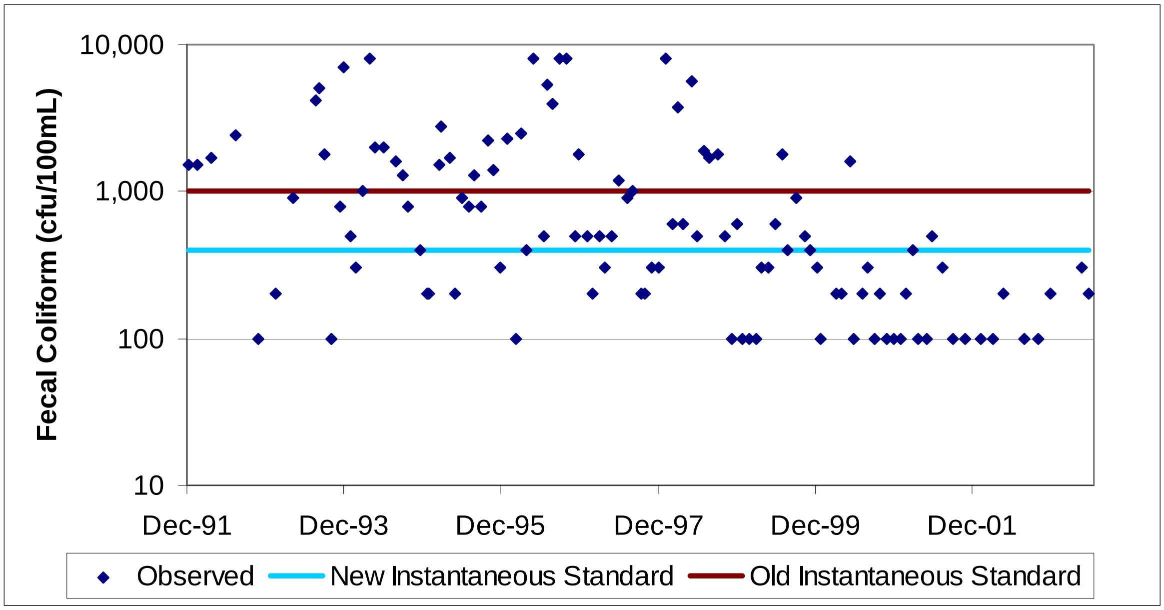

Figure 3-3. VADEQ monitored fecal coliform concentrations in Mill Creek.

Volunteer data in Mill Creek consisted of monthly fecal coliform samples collected by members of the Page County Water Quality Committee and processed by Tom Benzing at James Madison University, as shown in Figure 3-4.

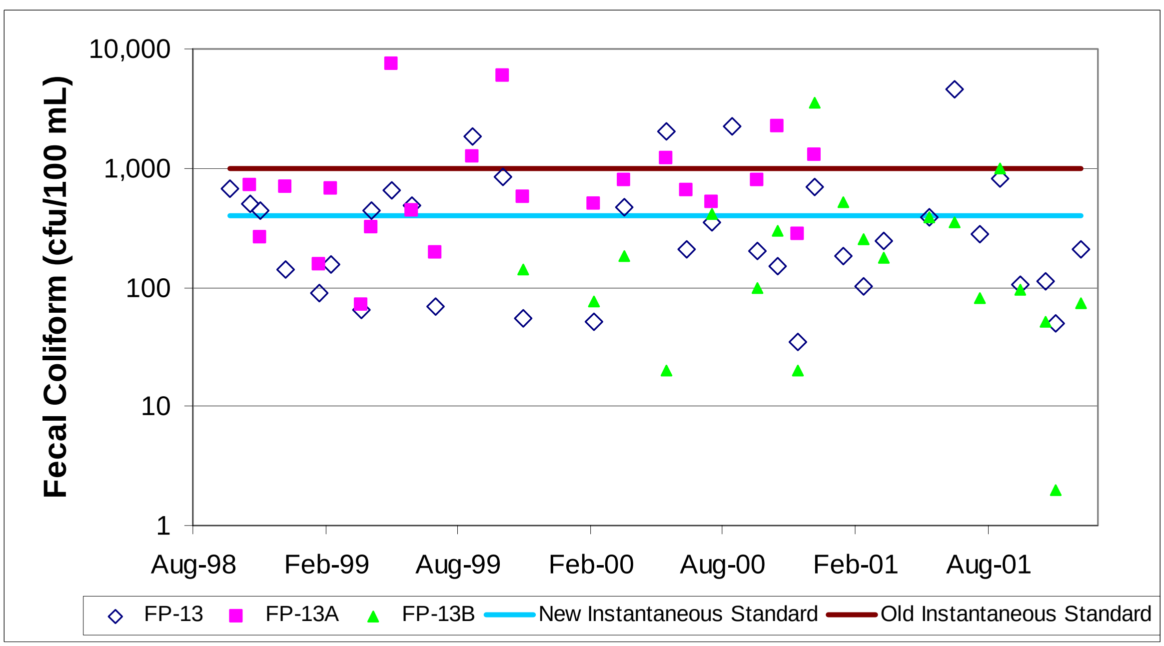

Figure 3-4. Volunteer monitored fecal coliform concentrations in Mill Creek.

The Membrane Filtration Technique (MFT) was used by VADEQ for the analysis of fecal coliform in water samples. The majority of the violations of the fecal coliform water quality standard shown in Figure 3.3 were observed prior to 1999, with a rapid reduction in the amount and range of observed concentrations since then. From 1991 through 1998, 34 out of 72 samples (47.2%) exceeded the instantaneous standard of 1,000 cfu/100 mL, while from 1999 through 2003, only 2 out of 40 samples (5.0%) exceeded the standard, showing a drastic improvement in water quality even before the initiation of this TMDL study. Because the water samples were collected on a monthly basis, the geometric mean criterion did not apply, as the geometric mean calculation requires 2 or more samples per month.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3-5). Mean monthly fecal coliform concentration was determined as the average of five to eight values for each month during 1991 through 1998, and as the average of three to four samples from 1999 through 2003; the number of values varied according to the available number of samples for each month in the 1991 to 2003 period of record.

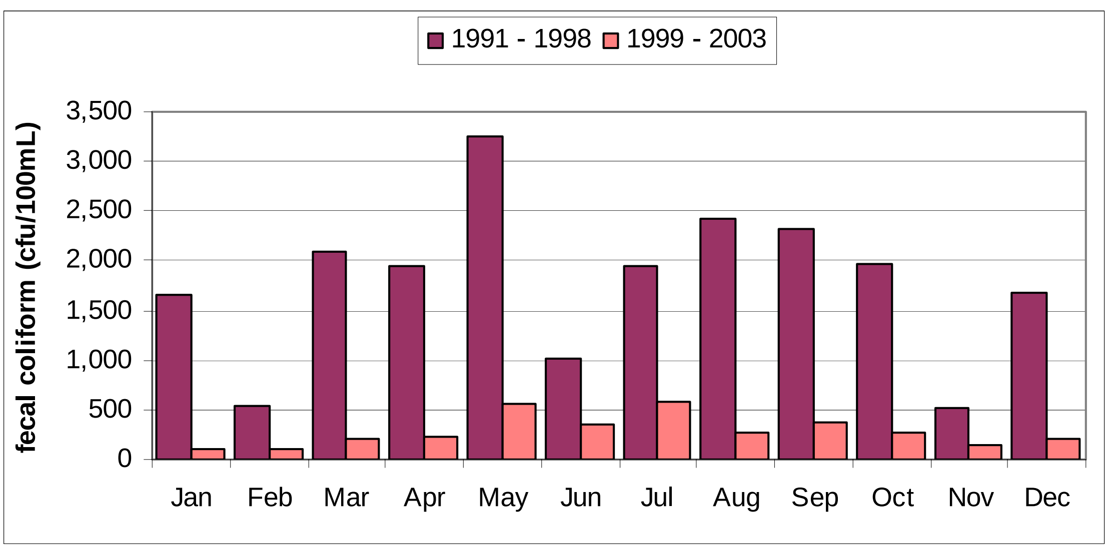

Figure 3-5. Impact of seasonality on fecal coliform concentrations.

The data show a somewhat random pattern without the strong seasonal variability shown in some agricultural watersheds. Typically, higher in-stream fecal coliform concentrations occur during the summer months and lower concentrations occur during the winter months. Lower fecal coliform concentrations in some months could be due to either very dry periods, or to periods of heavy rainfall that would dilute the impact of manure directly deposited in streams. Higher concentrations could be due to more time spent by livestock in stream, or to land applications of manure applied during wet periods when bacteria are more subject to transport via runoff. The high fecal coliform concentrations observed during March-May could also be due to a larger proportion of animal waste being applied prior to spring planting and during July-October for a winter cover crop and/or to create space in a farm's waste storage facility for animal waste generated during winter. Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000), where fecal coliform levels are equal to these maximum levels, the actual counts could be much higher, increasing the averages shown in Figure 3-5.

3.7.2. Bacteria Source Tracking

Limited bacteria source tracking (BST) was conducted to aid in identification of potential sources of fecal bacteria in the Mill Creek watershed. The BST samples were collected at the VADEQ ambient water quality monitoring station (1BMLC000.40) near the mouth of Mill Creek. The Antibiotic Resistance Analysis (ARA) procedure for *E. coli* was used in this study (Hagedorn *et al.*, 1999). A total of 12 monthly BST samples were collected from July 2003 through June 2004.

The monthly water quality samples collected for the BST analysis were also analyzed for *E. coli* and fecal coliform bacteria. As mentioned in Section 2.2.2, any sampling station with 12 or more *E. coli* samples must attain the new bacteria standard for *E. coli*, rather than the old standard for fecal coliform. Since 12 samples have been taken, the TMDL for Mill Creek will be developed to meet both the 30-day geometric mean *E. coli* standard of 126 cfu/100 mL and the instantaneous *E. coli* standard of 235 cfu/100 mL. The concentrations for both *E. coli* and fecal coliform bacteria in the BST samples are shown in Figure 3-6.

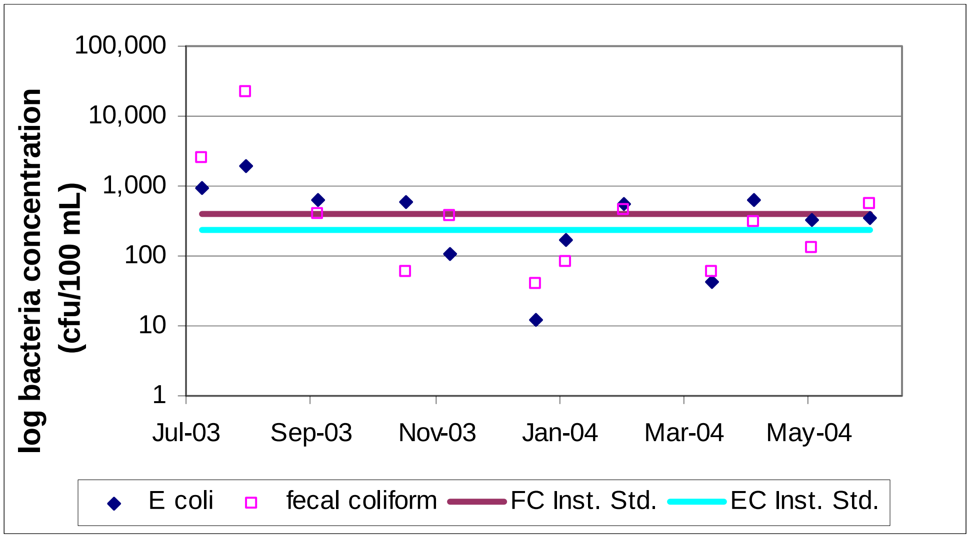

Figure 3-6. *E. coli* and fecal coliform concentrations in Mill Creek from bacterial source tracking (BST) samples.

A total of 48 isolates were analyzed for each BST sample. The ARA results are reported as the percentage of isolates acquired from samples that were identified as originating from either human, livestock, cats/dogs, or wildlife sources (Table 3-1). The concentration-weighted average percent contributions shown in the BST results (Figure 3-7) indicate that livestock are the major source of fecal bacteria, contributing 52% in Mill Creek. Wildlife was identified as the second most significant source accounting for an average of 25% of the fecal bacteria load. Human and pet sources were found to contribute averages of 16% and 7% of the fecal bacteria load, respectively. Due to the short time available for BST sample collection, no evaluation of the seasonal impacts could be made.

Table 3-1. Mill Creek BST results.

Date	Fecal coliform (cfu/100 mL)	E. coli (cfu/100 mL)	% Contribution Livestock	Wildlife	Human	Pet
07/21/03	2,500	940	29%	12%	25%	34%
08/11/03	22,000	1,900	63%	25%	12%	0%
09/15/03	400	650	58%	38%	4%	0%
10/27/03	60	610	84%	8%	8%	0%
11/17/03	370	104	38%	62%	0%	0%
12/29/03	40	12	41%	21%	17%	21%
01/12/04	80	166	63%	12%	0%	25%
02/09/04	440	560	21%	38%	33%	8%
03/22/04	60	42	71%	17%	0%	12%
04/12/04	300	630	50%	4%	42%	4%
05/10/04	130	330	8%	92%	0%	0%
06/07/04	540	340	79%	17%	4%	0%

	Livestock	Wildlife	Human	Pet
min	8%	4%	0%	0%
weighted-average	52%	25%	16%	7%
max	84%	92%	42%	34%

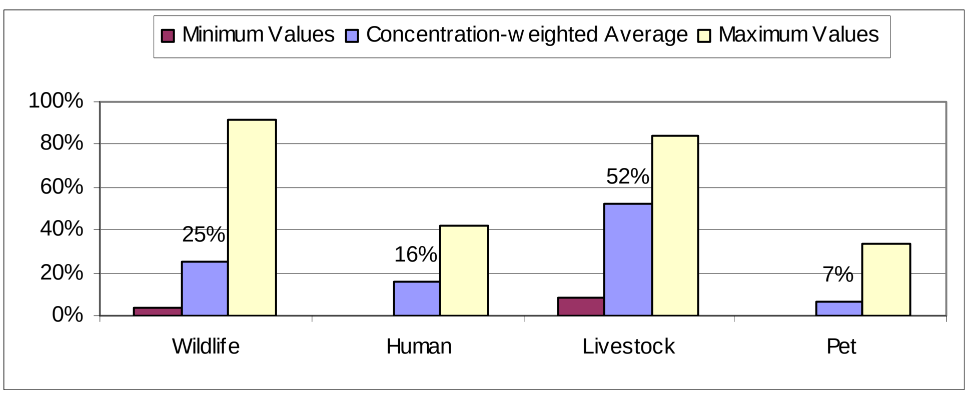

Figure 3-7. Minimum, maximum, and concentration-weighted average % contributions of bacteria from BST samples.

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Fecal coliform sources in the Mill Creek watershed were assessed using information from the following sources: VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Potential nonpoint sources of fecal coliform are described in detail in the following sections and summarized in Table 4-1. There are no permitted point sources of fecal coliform bacteria in the Mill Creek watershed, although there is one non-permitted source in the form of periodic sanitary sewer overflows (SSOs) from the Town of Stanley.

4.1. Humans and Pets

The Mill Creek watershed has an estimated population of 2,318 people (931 households at an average of 2.49 people per household; actual people per household varied according to sub-watershed). The population was calculated from area-weighted proportions of population by census 2000 block group areas covering the Mill Creek watershed (Census Bureau, 2000). Average household size was calculated as an average of average household sizes calculated for individual census block groups. The houses were broken into three age categories in order to assess potential bacteria contributions from each. The available age categories in the census 2000 data were pre – 1969, 1970 – 1989, and post – 1990. Households were categorized as either sewered or non-sewered. The non-sewered households were broken down into those having straight pipes, failing septic systems, and normally functioning systems.

Human sources were represented as bacteria transported to streams either from failing septic systems, via straight pipes discharging directly into streams, and as periodic sanitary sewer overflows (SSOs) from the Stanley Sewage Treatment Plant (STP).

Table 4-1. Potential fecal coliform sources and daily fecal coliform production by source in Mill Creek watershed.

Potential Source	Population in Watershed[h]		Fecal coliform produced ($\times 10^6$ cfu/head-day)
	First calibration period (1997)	Existing Conditions (2004)	
Humans	2,318	2,318	1,950[a]
Dairy cattle			
Milk cows	200	0	39,100[b]
Dry cows	50	0	39,100[b]
Heifers [c]	250	0	17,874[d]
Beef cattle	1,358	1,188	33,000
Pets	931	931	450[e]
Poultry			
Broilers	1,022,700	869,700	68[f]
Turkeys	163,800	135,800	93[f]
Pullets	51,000	51,000	68[f]
Layers (Broiler Breeders)	65,600	65,600	136
Sheep			
Ewes	38	30	12,000[f]
Lambs	76	60	12,000[f]
Horses	21	32	420[f]
Deer	156	156	347
Raccoons	66	66	50
Muskrats	92	92	25[g]
Beavers	8	8	0.2
Ducks	36 / 55	36 / 55	1250[f]
Geese	225 / 450	225 / 450	62.5

[a] Source: Geldreich (1978)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Source: Weiskel *et al*. (1996)
[f] Source: ASAE (1998)
[g] Source: Yagow (2001)
[h] Where two numbers are given, these reflect summer and winter populations, respectively.

4.1.a. Sewered Population

A portion of the watershed is served by the Stanley Sewage Treatment Plant, which is located outside of the watershed. Waste from sewered households was assumed to be properly treated by the Stanley STP. Sewered areas were identified from house locations on digital raster graphic (DRG) maps and the Stanley town boundary from census data maps. Area boundaries were further refined through consultation with the town STP personnel at the first watershed

Local Steering Committee meeting. Four hundred and fifty-one households were located in the sewered area of Mill Creek watershed.

4.1.b. Failing Septic Systems

A portion of the non-sewered households were estimated as having failing septic systems. Septic system failure can be evidenced by the rise of effluent to the soil surface, thereby by-passing soil filtration and die-off through competition with soil bacteria and other processes. Surface runoff can transport the effluent containing fecal coliform to receiving waters. The non-sewered portion of the watershed contained an estimated 480 households which were considered potential sources of bacteria from failing septic systems. Each non-sewered household was classified into one of three age categories (pre-1969, 1970-1989, and post-1989) based on population categories available in the 2000 census data. Professional judgment together with local steering meeting input was used to estimate septic system failure rates for houses in the three age categories as 20, 5, and 1%, respectively (Initial estimates based on R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 2.38 to 2.57 persons per household (Census Bureau, 2000)) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 2.49 persons/household was 4.86×10^9 cfu/day. A portion of this fecal coliform load may be transported to a stream during runoff. The number of failing septic systems estimated in the watershed is given in Table 4-2.

4.1.c. Straight Pipes

Another portion of the non-sewered households were estimated as having straight pipes. The number of straight pipes was estimated from the 2000 Census population in the watershed classified as "Lacking complete plumbing facilities". This population was divided by the average persons per household (2.49) for a total of 6.3 straight pipes in the watershed. During calibration, this number was further refined to just 0.4 straight pipes. This number refers to the potential contribution from this source, rather than an actual physical number of identified straight pipes. The number of houses estimated as having straight pipes was subtracted from the number estimated as having failing septic systems.

4.1.d. Sanitary Sewer Overflows (SSOs)

In the south end of the Mill Creek watershed, the Town of Stanley operates sanitary sewer lines that connect to the Stanley sewage treatment plant (STP), which is located outside of the watershed. The source of drinking water for Stanley is groundwater and the discharge from the STP is to the South Fork of the Shenandoah River. So under normal circumstances, the STP would have no impact on the water quality in Mill Creek. However, the pumping station on Aylor Grubbs Avenue, located in sub-watershed 7, has been prone to sanitary sewage overflows that periodically contribute bacteria in untreated sewage to the flow in Mill Creek. A time series of hourly flow volumes and bacteria loads has been developed for input into the model, as described in the following paragraph.

The Stanley STP has a permitted capacity of 0.300 million gallons per day (MGD), but currently treats approximately 0.156 MGD. The concentration of bacteria estimated for dilute wastewater was 500,000 cfu/100 mL (EPA, 2004). Therefore, the Stanley STP has an average daily bacteria load of 2.9523×10^{12} cfu/day. Overflows are commonly caused by infiltration of stormwater during heavy rains and runoff so that the capacity of the pumping stations is exceeded. Overflow events reported to VADEQ were mostly anecdotal with the STP operator or neighborhood resident reporting either beginning and ending times of the overflow, estimated duration of the overflow, or an estimated volume of overflow. VADEQ records indicated a total of 33 SSO events from 1992 through 2004. Based on VADEQ records of reported overflows, a time series was constructed that estimated the beginning and ending of each event, the total volume of overflow, and the fraction of the daily flow that was overflowing. The fraction of the daily bacteria load was assumed to be equal to the fraction of the daily flow that was overflowing. A complete list of events and the spreadsheet used to calculate daily bacteria loads for each event are in Appendix K.

4.1.e. Pets

Assuming one pet per household, there were 931 pets in the Mill Creek watershed. Fecal coliform is produced by a dog at a rate of 0.45×10^9 cfu/day (Weiskel *et al.*, 1996), which is assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is the same as for "Total No. of Households" listed in Table 4-2. Pet waste was generated in the rural residential and urban residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4-2. Estimated household population and distribution used in estimating Human bacteria contributions in Mill Creek watershed.

Sub-watershed	Non-sewered houses in each age category (no.)[a]			Failing septic systems (no.)	Straight Pipes (no.)[b]	Sewered households (no.)	Total No. of Households[c]
	Pre-1969	1970-1989	Post-1990				
MC-1	16	10	3	2.2	1.6	58	88
MC-2	41	23	12	8.5	1.0	55	130
MC-3	45	23	10	8.3	2.0	113	190
MC-4	61	48	23	13.1	1.7	3	135
MC-5	1	0	0	0.1	0	0	1
MC-6	34	24	12	8.0	0	120	189
MC-7	45	34	17	10.8	0	102	198
Total	242	162	75	51.1	6.3	451	931

[a] Some totals may appear to be slightly more or slightly less due to round-off of numbers for individual sub-watersheds.
[b] This original estimate of straight pipes was refined during calibration to represent only 0.4 of a household.
[c] Since an average of one pet per household was assumed, the pet population is the same as the Total No. of Households for individual sub-watersheds, as well as the overall watershed total.

4.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop, pasture, and hay land.

4.2.a. Distribution of Dairy and Beef Cattle in the Mill Creek Watershed

There was only one dairy operation in the Mill Creek watershed, which went out of business in 1998. From conversations with the local Virginia Cooperative Extension agent, it was determined that there were 200 milk cows, 50 dry cows, and 250 heifers in the operation, as shown earlier in Table 4-1. As of 2004 there were no active dairy operations within the Mill Creek watershed, as shown in Table 4-3.

Table 4-3. Distribution of dairy and beef cattle among Mill Creek sub-watersheds.

Sub-watershed	Dairy cattle		Beef cattle	
	1997	2004	1997	2004
MC-1	0	0	128	112
MC-2	500	0	284	248
MC-3	0	0	303	265
MC-4	0	0	225	197
MC-5	0	0	2	2
MC-6	0	0	233	204
MC-7	0	0	183	160
Total	500	0	1,358	1,188

The beef population in each Mill Creek sub-watershed for the first period of calilbration (1997) was based on a carrying capacity of 0.36 head/acre of pasture applied to the pasture acreage in each sub-watershed. Estimates for existing conditions (2004) were based on a 12.49% reduction in Page County Agricultural Census beef numbers between 1997 and 2002 (USDA-NASS, 2002).

Beef and dairy cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (e.g., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited on any given land area will vary throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream.

a) Cows were confined according to the schedule given in Table 4-4.

b) When the milk cows were not confined, they spent 100% of the time on pasture and/or in streams, if access was available. Cattle were assumed to be on pasture when not in confinement. No beef cattle were confined in the watershed.

c) Cows in riparian pasture areas (pastures adjacent to, or containing, streams) have stream access along 7,853 linear feet of stream as shown in Table 4-5.

d) Cows with stream access spend varying amounts of time in and around the stream during different seasons (Table 4-4). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.

Of the fecal coliform generated in waste by livestock with stream access, 30% is deposited in and around the stream. The remaining 70% of the manure associated with this time is deposited on pasture areas.

Table 4-4. Time spent by dairy cattle in confinement and in and around streams (First calibration period only).

Month	Time spent in confinement (%) by Dry cows, milk cows, and heifers	Time spent in and around streams (hours/day)[a]
January	83%	0.17
February	83%	0.18
March	74%	0.34
April	66%	0.49
May	66%	0.79
June	65%	1.11
July	64%	1.46
August	64%	1.5
September	65%	0.6
October	66%	0.4
November	74%	0.31
December	83%	0.23

[a] Time spent in and around the stream by cows that have stream access.

Table 4-5. Pasture acreages with stream access.

Sub-watershed	Pasture (Acres)	Pasture (%)[a]	Perennial Stream Access (Linear feet)
MC-1	393	10.91	1,093
MC-2	1,102	30.59	2,686
MC-3	1,137	31.56	842
MC-4	0	0.00	0
MC-5	10	0.27	129
MC-6	960	26.66	3,104
MC-7	0	0.00	0
Total	3,602	-	7,854

[a] Percent of pasture area contiguous to streams in each sub-watershed.

A sample calculation for distributing the waste from dairy cattle to different land use types and stream in sub-watershed MC-2 is shown in Appendix B. One loafing lot area was simulated during the first calibration period in conjunction with the one dairy operation in Mill Creek. No loafing lots were simulated under Existing Conditions. The resulting number of cattle assigned to confined, pasture, and "in and around streams" in each sub-watershed are given for dairy cattle in Table 4-6 for the first calibration period and for beef cattle in Table 4-7 for Existing Conditions.

Table 4-6. Distribution of the dairy cattle population[a] (First calibration period only).

Month	Confined	Loafing Lot	Pasture	Stream[b]	Total
January	302	21.0	186.8	0.2	510
February	302	21.0	186.8	0.2	510
March	112	50.4	346.9	0.7	510
April	84	58.8	366.2	1.0	510
May	84	58.8	365.5	1.7	510
June	84	58.8	364.8	2.4	510
July	84	58.8	364.1	3.1	510
August	84	58.8	364.0	3.2	510
September	84	58.8	365.9	1.3	510
October	84	58.8	366.3	0.9	510
November	112	50.4	347.0	0.6	510
December	302	21.0	186.8	0.2	510

[a] Population is given in Animal Unit (AU) equivalents, where 1 AU = 1,000 lbs. Population includes milk cows, dry cows, and heifers, where 200 Milk Cows x 1.4 AU ea. + 50 Dry Cows x 1.4 AU ea. + 250 Heifers x 0.64 AU ea. = 510 AU.

[b] Number of dairy cattle defecating in and around the stream.

Table 4-7. Distribution of the beef cattle population (Existing Conditions)

Months	Confined	Pasture	Stream[a]	Total
January	0.0	1,365.1	1.1	1,366.2
February	0.0	1,602.4	1.4	1,603.8
March	0.0	1,648.7	2.6	1,651.3
April	0.0	1,694.9	3.9	1,698.8
May	0.0	1,739.8	6.5	1,746.4
June	0.0	1,784.5	9.4	1,793.9
July	0.0	1,828.7	12.7	1,841.4
August	0.0	1,875.5	13.4	1,888.9
September	0.0	1,931.0	5.5	1,936.4
October	0.0	1,185.8	2.2	1,188.0
November	0.0	1,245.6	1.8	1,247.4
December	0.0	1,305.4	1.4	1,306.8

[a] Number of beef cattle defecating in and around the stream.

4.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams from either dairy (Table 4-6) or beef cattle (Table 4-7) only occurred where non-fenced pasture areas were contiguous to streams. Manure loading increased during the warmer months when cattle spend more time in the stream compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed was 113,811 lbs. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, was 6.26×10^{13} cfu/day. Part of the fecal coliform deposited in the stream stays suspended in the water column while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that primarily suspended fecal coliform bacteria are transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.c. Direct Manure Deposition on Pastures

The majority of fecal coliform loading to pasture areas occurs during time spent by both dairy (Table 4-6) and beef (Table 4-7) while grazing. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure produced per day. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure for each type of livestock. The total amount of fecal bacteria produced by all types of cattle was divided by the pasture acreage in each sub-watershed to obtain fecal bacteria loading (cfu/ac-day) on pasture. Because the confinement schedule of cattle changes with season, manure and fecal coliform loading on pasture also varies by season.

Pasture areas in Mill Creek have an average annual cattle manure loading of 11,648 lb/ac-year. The fecal coliform loading from cattle on a daily basis, averaged over the year, is 1.96×10^{16} cfu/ac-day for pasture and 5.81×10^{12} for hay. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff transports part of the remaining fecal coliform to receiving waters.

4.2.d. Land Application of Liquid Dairy Manure

A typical dairy milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Dry cows and heifers were assumed to produce only solid manure. Based on the monthly confinement schedule (Table 4-4) and the number of milk cows (Table 4-3), the annual liquid dairy manure production in the watershed for the first period calibration was 531,377.5 gallons. For existing conditions, no liquid dairy manure was either produced or applied.

During the first period of calibration, liquid manure was applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure was applied on the soil surface to rotational hay and no-till corn, and was incorporated into the soil for corn in conventional tillage. In fall, liquid manure was incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. In all months except December and January, liquid manure can be surface-applied to pasture. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule for all types of animal manure for existing conditions is given in Table 4-8.

Table 4-8. Schedule of cattle and poultry waste application in the Mill Creek watershed for Existing Conditions.

Month	Liquid manure applied (%)[a]		Solid manure (%)[a]		Poultry litter applied (%)	
	Crops	Pasture	Crops	Pasture	Crops	Pasture
January	0	0	0	0	0	0
February	0	0	0	0	1	1
March	0	0	0	0	30	30
April	0	0	0	0	25	25
May	0	0	0	0	5	5
June	0	0	0	0	5	5
July	0	0	0	0	2	2
August	0	0	0	0	2	2
September	0	0	0	0	10	10
October	0	0	0	0	10	10
November	0	0	0	0	10	10
December	0	0	0	0	0	0

[a] As percent of annual load applied to each land use type.

4.2.e. Land Application of Solid Manure

Solid manure produced by dry cows and heifers during confinement was collected for land application and only simulated during the first period of calibration. It was assumed that milk cows produced only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4-9. Solid Manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows and heifers in each sub-watershed (Table 4-3) and their confinement schedules (Table 4-4). Fecal coliform concentrations (cfu/lb) in solid manure varied by livestock type (Table 4-9).

Table 4-9. Estimated cattle population, typical weights, solid manure production, and fecal coliform concentrations in fresh solid manure by individual cattle type.

Type of cattle	Population		Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure (× 10^6 cfu/lb)
	1997	2004			
Dry cow	50	0	1,400[a]	115.0[b]	340[c]
Heifer	250	0	640[d]	40.7[a]	439[c]

[a] Source: ASAE (1998)
[b] Source: MWPS (1993)
[c] Based on per capita fecal coliform production per day (Table 4-1) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).

For existing conditions, no solid manure was collected and stored from confined animals. For the first period of calibration, solid manure was applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As is the case of liquid manure, solid manure was only applied to cropland during February through May, October, and November. For Existing and Future Conditions, no solid manure was produced in the watershed from livestock. Solid manure can be applied to pasture during the whole year, except December and January. The method of incorporating solid manure applied to cropland and pasture was assumed to be the same as the method used with liquid dairy manure. The application schedule for solid manure was given in Table 4-8.

4.3. Poultry

Sub-watershed poultry populations (Table 4-1) were initially estimated from VADCR's confined animal feeding operations (CAFO) facilities database, and later refined by VADEQ CAFO inspectors from CAFO permits on poultry operations located within the watershed for various time frames. Poultry litter production was estimated from the poultry population after accounting for the time when the houses were not occupied (Table 4-10). It is not known which type of poultry litter (broiler or broiler breeder or turkey) is applied to which agricultural land use category. Therefore, a weighted average fecal coliform concentration was estimated for poultry litter based on relative proportions of litter from all poultry types and their respective fecal coliform contents (Table 4-10); this concentration was used to calculate fecal coliform loading to all land use categories receiving poultry litter.

Table 4-10. Estimated daily litter production and fecal coliform content for individual poultry types, and weighted average fecal coliform content.

Poultry Type	Typical Weight (lb)[a]	Production cycles (per year)[b]	Occupancy factor[c]	Litter produced per bird		Fecal coliform content ($\times 10^9$ cfu/lb)[f]	Weighted average fecal coliform content ($\times 10^9$ cfu/lb)
				(lb/cycle)[d]	(lb/day)[e]		
Broiler Breeder[g]	4	1.09	0.96	30.0	0.256	1.46	0.78
Broiler	2	6	0.79	2.6	0.17	1.65	
Turkey	15	5	0.87	18.0	0.705	0.33	

[a] Source: ASAE (1998)
[b] Based on information from VADCR and producers
[c] Fraction of time when the poultry house is occupied; layer – 46 weeks/48 weeks; broiler – 48 days/61 days; turkey (5 cycles) – 45 weeks/52 weeks
[d] Source: VADCR (1993)
[e] Litter produced per bird per day is equal to the product of production cycles per year and litter produced per cycle divided by number of days in a year.
[f] Fecal content in litter is equal to fecal coliform produced per day per bird (Table 4-1) multiplied by the occupancy factor, divided by the litter produced per day per bird.
[g] Broiler Breeders were considered equivalent to Layers.

Because poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. The estimated production rate of poultry litter in the Mill Creek watershed is 3.8×10^4 lb/year, which corresponds to a fecal coliform production rate of 1.49×10^{16} cfu/year. For calibration/validation and Existing Conditions, poultry litter was applied at the rate of 3.5 tons/ac-year to cropland (which receives priority for application), 2.5 tons/ac-year for pasture, and 1 ton/ac-year for hay. For Future Conditions, poultry litter was assumed to be applied at the rate of 1.5 ton/ac-year for cropland and 1 ton/ac-year for pasture and hayland, in line with phosphorus-based recommendations. Poultry litter receives priority after all liquid manure has been applied (i.e., it is applied before solid cattle manure is considered). The schedule and method of incorporation of poultry litter applied to cropland and pasture was the same as used for cattle manure application. The application schedule of poultry litter is given in Table 4-8. Where storage facilities were not available for poultry litter, it was assumed that monthly spreading of poultry litter occurred in the watershed. Where storage facilities were available, poultry litter was not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 409.9 acres (89%) of cropland; 1,739.3 acres (57.8%) of pasture; and 1206.4 acres (97%) of hay.

4.4. Sheep

The sheep population (Table 4-1) was estimated based on discussions with nutrient management specialists and observations of the watershed. The sheep herd was composed of lambs and ewes, with the lamb population estimated as twice the ewe population. The sheep were kept on pasture. The estimated sheep population for each sub-watershed is shown in Table 4-11. Sheep are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep was added to the load applied to pasture.

Table 4-11. Sheep Population in Mill Creek Sub-Watersheds (2004)

Sub-watershed	1997		2004	
	Ewe Population	Lamb Population	Ewe Population	Lamb Population
MC-1	4	8	3	6
MC-2	8	16	6	12
MC-3	8	16	7	14
MC-4	6	12	5	10
MC-5	0	0	0	0
MC-6	7	14	5	10
MC-7	5	10	4	5
Total	38	76	30	60

Pasture has an average annual sheep manure loading of 17.47 lb/ac-year. The fecal coliform loading from sheep on a daily basis averaged over the year was 2.4×10^8 cfu/ac-day for pasture.

4.5. Horses

The horse population in the Mill Creek watershed was estimated through observations in the watershed and communication with local producers. The existing (2004) horse population was estimated from a windshield survey of the watershed. Estimates for historical conditions (1997) were based on proportional county-wide Page County Agricultural Census horse numbers between 1997 and 2002 (USDA-NASS, 2002). The distribution of horse population among the sub-watersheds is listed in Table 4-12. Horses were not usually confined and tended not to wade, or defecate, in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to pasture and hayland. Annual daily fecal coliform loadings from horses averaged over the pasture and hayland areas in the entire watershed were 3.79×10^7 cfu/ac-day and 3.78×10^7 cfu/ac-day, respectively.

Table 4-12. Horse Population in Mill Creek Sub-Watersheds.

Sub-watershed	Horse Population	
	1997	2004
MC-1	0	0
MC-2	17	26
MC-3	0	0
MC-4	0	0
MC-5	0	0
MC-6	4	6
MC-7	0	0
Total	21	32

4.6. Wildlife

Fecal coliform contributions from wildlife waste can be from excretion on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents was used to estimate wildlife populations. Wildlife species that were estimated to be in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4-1) along with preferred habitat and habitat area (Table 4-13).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat area each occupied (Table 4-13). Fecal matter produced by deer that was not directly deposited in streams was distributed among pastures and forest. Raccoons deposited their waste in streams and forests. Muskrats deposited their waste in streams, forest, and cropland.

Table 4-13. Wildlife habitat description and extent, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Extent of habitat	Population Density[c]	Direct fecal deposition in streams (%)
Deer	Entire Watershed	8,221.3 ac	12.2 /sq.mi.	1%
Raccoon	Forest area within an 180-m buffer of perennial streams[b]	654.3 ac	50 /sq.mi.	10%
	Forested area outside of the 180-m buffer	939.2 ac	10 /sq.mi.	10%
Muskrat	Based on linear stream length and riparian cropland[b]	0.109 mi	16 /mi	25%
	Based on linear stream length and riparian pasture[b]	4.88 mi	8 /mi	25%
	Based on linear stream length and lake or pond shoreline[b]	5.15 mi	10 /mi	25%
Beaver	Forest and pasture within 100-m of perennial streams and impoundments	1,304.5 ac	3.9 /sq.mi.	50%
Geese[a]	All land uses within 100-m of perennial streams	1,442.2 ac	100 /sq.mi. 200 /sq.mi.	5%
Wood Duck[a]	All land uses within 100-m of perennial streams	1,442.2 ac	16.2 /sq.mi. 24.2 /sq.mi.	5%

[a] Based on initial estimates provided by Joe Lehman, refined by consensus of stakeholders at the Second Local Steering Committee meeting (October 20, 2004), and through calibration.

[b] Adapted from procedures suggested by VDGIF personnel.

[C] The two sets of population numbers represent summer and winter populations, respectively, for these migrating species.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the entire watershed was deemed to be suitable habitat for deer, whereas muskrat population was tied to combinations of linear stream length and riparian land uses. Therefore, a sub-watershed with greater stream length, surface water shoreline, and riparian pasture would have more muskrats than a predominantly cropped sub-watershed with shorter stream length. Distribution of wildlife among sub-watersheds is given in Table 4-14.

Table 4-14. Distribution of wildlife among sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese		Wood Duck	
					Summer	Winter	Summer	Winter
MC-1	17	10	9	1	29	58	5	7
MC-2	31	15	28	2	60	120	10	15
MC-3	33	9	13	1	25	50	4	6
MC-4	25	9	6	1	27	54	4	7
MC-5	0	0	1	0	2	4	0	0
MC-6	27	18	25	2	62	124	10	15
MC-7	23	7	11	1	20	40	3	5
Total[a]	157	66	92	8	225	450	37	55

[a] Totals may not always be equal to the sum of the numbers for individual sub-watersheds, due to round-off of the displayed numbers.

4.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4-15. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4-15.

Table 4-15. Annual Existing Condition fecal coliform load inputs in the Mill Creek watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	62.6	0.30%
Wildlife in stream	7.1	0.03%
Straight pipes	0.7	0.003%
SSOs	1.7	0.01%
Loading to land surfaces		
Cropland	235.8	1.11%
Hay	202.9	0.96%
Pasture	20,318.9	95.79%
Residential[a]	251.9	1.19%
Forest	130.0	0.61%
Total	21,211.5	100%

[a] Includes loads received from both High and Low Density Residential due to failed septic systems and pets.

From Table 4-15, it is clear that nonpoint source loadings to the land surface are almost 300 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure) and proximity to streams also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

CHAPTER 5: MODELING PROCESS FOR BACTERIA TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling processes, input data requirements, model calibration procedures and results, and model validation results are discussed.

5.1. Model Description

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrological Simulation Program – FORTRAN, Windows Version (HSPF) (Duda *et al.*, 2001) was used to model fecal coliform transport and fate in the Mill Creek watershed. The ArcGIS 8.1 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda *et al.*, 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While

HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

5.2. Selection of Sub-watersheds

Mill Creek is a moderately sized watershed (8,221 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into seven sub-watersheds as shown previously in Figure 3-1. The impaired section of Mill Creek (VAV-B38R) begins at the headwaters and runs to the confluence with the South Fork of the Shenandoah River. Small tributaries into Mill Creek are unnamed. The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment, though flow in three of the sub-watersheds (3, 4, and 7) is primarily intermittent. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, pollutant sources, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Mill Creek watershed are discussed below.

5.3.1. Climatological Data

Since the time-step used in water quality simulations was 1 hour, hourly climatic input data was required. Meteorological data used for Mill Creek were based on meteorological inputs used for TMDL modeling in the neighboring Hawksbill Creek watershed (Tetra Tech, 2004). These data were obtained primarily from the Luray (445096) National Weather Service COOP station. Additional data used to extend the period of record through 2003 and to add climate parameters not used with the LSPC model were obtained from the Dale Enterprise (442208), Edinburg (442663), Big Meadows (440720), and Washington Dulles Airport (448903) stations. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are described in APPENDIX D.

5.3.2. Hydrology Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land use category for each sub-watershed. Values for the hydrologic parameters were estimated based on local conditions where possible; otherwise hydrologic parameters calibrated for the Hawksbill Creek TMDL study were used (Tetra Tech, 2004). For the stream reach representing each sub-watershed, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Duda *et al.*, 2001). These parameters were estimated for representative channel cross-sections from topographic maps for each sub-watershed. Information on stream geometry in each sub-watershed of each watershed is presented in Table 5-1. Hydrology parameters required for the PWATER, IWATER, and HYDR ADCALC sub-modules are listed in the HSPF Version 11 User's Manual (Bicknell *et al.*, 1997). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are also given in the HSPF User's Manual (Bicknell *et al.*, 1997). Runoff estimated by the hydrologic component of the model then becomes the vehicle for simulating washoff and transport of the water quality constituents.

Table 5-1. Stream Characteristics of Mill Creek.

Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
MC-1	1.776	15	0.50	0.0027
MC-2	2.650	11.7	0.50	0.00078
MC-3	1.023	5.75	0.25	0.0038
MC-4	1.121	1.91	0	0.0040
MC-5	0.123	12.48	0.35	0.0040
MC-6	2.808	2	0.10	0.0036
MC-7	0.944	6	0	0.0048

5.4. Land Use

Land use categories were based on 1992 National Land Cover Dataset (NLCD) data (MRLC, 1999). The 13 land cover types were consolidated into seven categories based on similarities in hydrologic features and waste application/production practices (Table 5-2). These categories were assigned pervious and impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules in HSPF. Land use data were used to select several hydrology and water quality parameter values for the simulations. Land use distribution in the seven sub-watersheds as well as in the entire Mill Creek watershed is presented in Table 5-3 and graphically in Figure 5-1.

Table 5-2. Consolidation of NLCD land cover categories for Mill Creek watershed.

TMDL Land Use Categories	Pervious/ Impervious[a] (Percentage)	NLCD Land Cover Categories (Land Cover Code)
Cropland	Pervious (100%)	Row crops (82)
Pasture Hay[b]	Pervious (100%)	Pasture/Hay (81) Quarries/strip mines/gravel pits (32)[c]
Forest	Pervious (100%)	Deciduous forest (41) Evergreen forest (42) Mixed forest (43) Woody wetlands (91) Emergent herbaceous wetlands (92)
Low Density Residential	Pervious (88%) Impervious (12%)	Low Density Residential (21) Transitional (33)
High Density Residential	Pervious (65%) Impervious (35%)	High density residential (22)
Commercial	Pervious (65%) Impervious (35%)	Commercial/industrial/transportation (23)
		Open water (11)

a Percent perviousness/imperviousness information was used in modeling (described in Section 5.4).

b The NLCD Pasture/Hay category was divided into separate categories based on the ratio of pasture and hay assessed by VADCR in the 2002 Virginia Statewide Nonpoint Source Assessment for state hydrologic unit B18, which contains Mill Creek (Yagow *et al.*, 2002).

c The one watershed area that fell in this category was ground-truthed and found to have been converted into pasture.

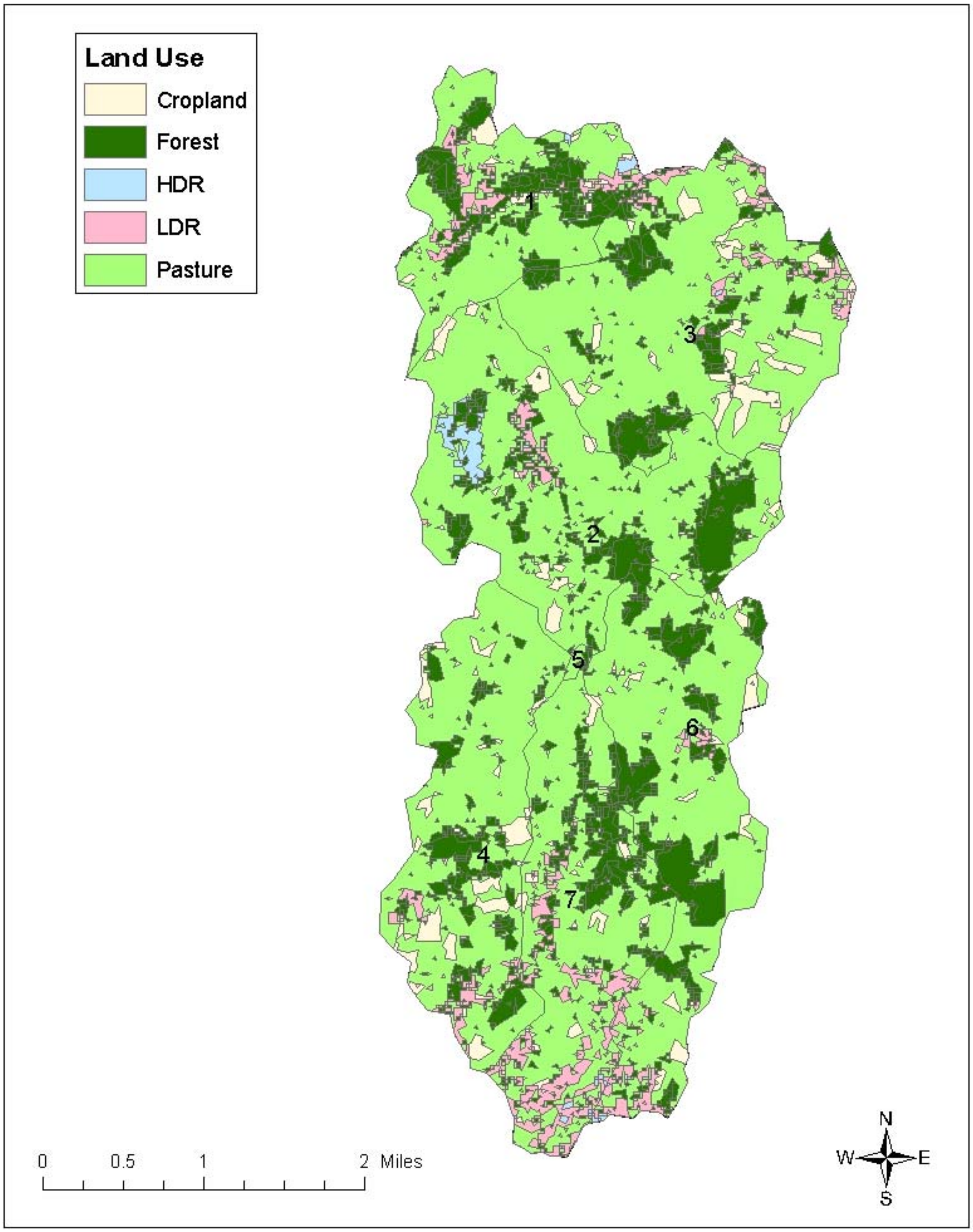

Figure 5-1. Mill Creek Watershed Land Use.

Table 5-3. Land use distribution in the Mill Creek watershed (acres).

Land use	**Sub-watersheds**							**Total**
	MC-1	**MC-2**	**MC-3**	**MC-4**	**MC-5**	**MC-6**	**MC-7**	
Cropland	37	68	139	119	0	56	40	459
Pasture	379	862	889	664	7	691	533	4,025
Hay	156	356	367	274	3	285	220	1,660
Forest	241	321	268	207	4	338	215	1,593
Low density residential - pervious	62	25	59	35	0	47	144	372
High density residential - pervious	0	0	0	0	0	1	2	2
Commercial - pervious	2	0	1	0	0	0	0	3
Low density resid. - impervious	8	3	8	5	0	6	20	51
High density resid. - impervious	0	0	0	0	0	1	3	5
Commercial - impervious	5	0	1	0	0	1	0	8
Total	**891**	**1,636**	**1,731**	**1,305**	**13**	**1,426**	**1,178**	**8,180**

5.5. Accounting for Pollutant Sources

5.5.1. Overview

There were no permitted VPDES point sources of bacteria in Mill Creek watershed. There were, however, a number of poultry confined animal feeding operations (CAFOs) operating with no-discharge permits. Additionally, sanitary sewer overflows (SSOs) from sewer lines operated by the Town of Stanley are a periodic non-permitted source of bacteria.

Bacteria loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Bacteria that were land-applied or deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

A spreadsheet-based software was used to generate the nonpoint source fecal coliform inputs to the HSPF model, the Bacteria Source Load Calculator (Zeckoski *et al.*, 2004). The Bacteria Source Load Calculator (BSLC) takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. The BSLC allows direct deposition in the stream by dairy cows, ducks, and geese to occur only during daylight hours. The BSLC also calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure. For modeling existing conditions in Mill Creek, half of the generated poultry litter was assumed to be exported out of the watershed, as estimated by the local watershed advisory committee.

5.5.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_0 10^{-Kt} \qquad \textbf{[5-1]}$$

where: C_t = concentration or load at time t,

C_0 = starting concentration or load,

K = decay rate (day^{-1}),

and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Mill Creek watershed (Table 5-4).

Table 5-4. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Cited in Crane and Moore (1986)
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Cited in Crane and Moore (1986)
Poultry litter	Soil surface	0.035	Giddens *et al.* (1973)
		0.342	Crane *et al.* (1980)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.

- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used assuming that a majority of manure piles are not covered.

- Poultry waste in pile/house: Because no decay rates were found for poultry waste in storage, a decay rate of 0.035 day^{-1} was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day^{-1} (Table 5-4) because fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in APPENDIX C. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface, and was represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.10 day^{-1} was used.

5.5.3. Modeling Point Sources

The one point source present in the watershed is not permitted. The sanitary sewer overflows from the Town of Stanley are modeled as a time series of additional flow and bacteria loads during the periods of overflow as discussed previously in Chapter 4:.

5.5.4. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4:. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Bacteria loads calculated for manure applications were reduced by appropriate storage die-off factors on a daily basis, prior to calculating loadings to cropland and pasture. Fecal coliform loadings to each sub-watershed in the Mill Creek watershed are presented in APPENDIX F. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland as described in Chapter 4:. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of liquid dairy manure and solid manure as described in Chapter 4:. Applied fecal coliform loadings to pasture were reduced to account for die-off during storage. For modeling, the monthly

fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.

3. Loafing Lot: Loafing lots received manure deposited by cows during the time they spend on the loafing lots (Table 4-6 and Table 4-7). This was applicable only to the first period of calibration when a dairy loafing lot was simulated. Fecal coliform loads resulting from direct waste deposition by cows in a particular sub-watershed were distributed uniformly over the entire loafing lot acreage in each sub-watershed.

4. Low Density Residential: Fecal coliform loading on rural residential area came from failing septic systems, wildlife and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential pervious land use areas. Impervious areas (Table 5-2) received constant loads of 1.0×10^7 cfu/acre/day.

5. High-Density Residential: Fecal coliform loading to the high density residential land use came from pets in these areas; the impervious load was assumed to be a constant 1.0×10^7 cfu/acre/day (USEPA, 2000).

6. Forest: Wildlife not defecating in streams, cropland, and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife in forests was applied uniformly over the forest areas.

5.5.5. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 4. Contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 7.5 cfu/100mL for interflow and 5 cfu/100mL for groundwater.

5.6. Accounting for Best Management Practices (BMPs)

The Virginia Department of Conservation and Recreation tracks all agricultural best management practices (BMPs) that are cost-shared in Virginia. Table 5-5 contains a summary of currently installed BMPs that impact bacteria loading in the Mill Creek watershed.

Table 5-5. Installed BMPs Currently Impacting Bacteria Loads in Mill Creek

Sub-watershed	BMP	Extent Installed	Units	Year Installed
3	SL-6[a]	400	Linear feet	2002
	WP-4[b]	1	System	1991
		3	System	1999
4	WP-4[b]	2	System	1990
		2	System	1991
		1	System	1995
6	WP-4[b]	1	System	1997
		1	System	1999
7	WP-4[b]	1	System	1999
		1	System	2000
		1	System	2003

[a] SL-6 = Grazing Land Protection (fencing)

[b] WP-4 = Animal Waste Control Facility (poultry litter storage shed)

The SL-6 practice was modeled by reducing livestock stream access by the ratio of "Extent Installed" to the total length of perennial streams in the affected sub-watershed. The WP-4 practice was modeled by shifting the monthly distribution of manure application. It was assumed that poultry operations without storage spread manure more evenly throughout the year (excluding the winter months of December and January when they wouldn't spread). With installed WP-4s, larger proportions of manure were applied in spring just before planting, slightly smaller amounts just after harvest in the fall, with even smaller monthly amounts in between.

Phosphorus (P)-based nutrient management for poultry operations was assumed to be in full effect for "Future" conditions. The estimated current levels of poultry manure application rates were reduced for "Future" conditions included in the modeling for the TMDL allocation scenarios to rates mandated by the current nutrient management standards (VADCR, 1995), as shown in Table 5-6. Application rates were estimated in consultation with the regional VADCR Nutrient Management Specialist.

Table 5-6. Poultry Manure Application Rates (lbs/ac-yr)

Modeling Scenario	Cropland	Pasture	Hay
Existing	7,000	5,000	2,000
Future	3,000	2,000	2,000

5.7. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the water quality component are presented.

5.7.a. Hydrology

Mill Creek used the hydrologic parameter values that were calibrated for neighboring Hawksbill Creek (Tetra Tech, 2004) as observed stream flow was not available within the Mill Creek watershed. Many of the stream reaches in Mill Creek are intermittent in nature and usually run dry during portions of the year. This was not observed in the model of Mill Creek created with the calibrated parameter values from Hawksbill Creek, but this was accepted as a limitation of not having observable flow from Mill Creek itself for calibration. Minor adjustments were made to some of the hydrology parameters – INFILT (0.13 to 0.15), AGWRC (0.99 to 0.98), and DEEPFR (0.29 to 0.23) – in order to assist with calibration of the water quality parameters. A complete list of all hydrologic parameters and their values is shown at the end of this section in Table 5-9.

5.7.b. Water Quality calibration

Direct Deposition of Manure at Very Low Flows

A modification of the low-flow stage cutoff method (Benham *et al.*, 2004) was used for the water quality calibration and allocation scenarios for the Mill Creek watershed. Direct deposition of manure in streams by livestock was modeled at greatly reduced levels (multiplied by 0.001) when stream depths approached zero. Under extremely low flow conditions, one animal defecating once in a stream reach can result in a violation of the instantaneous water quality standard. Since it is unlikely that animals will be wading in or drinking from the stream during extremely low flow, this method was developed. If direct deposition of manure by livestock is simulated at extremely low flow conditions, it can cause unrealistically high numbers of violations, make calibration difficult, and adversely affect the quality of the final calibration.

In order to more accurately simulate the water quality conditions at Mill Creek, we used a stage (stream depth) of 3 inches as a threshold for cattle direct deposition of manure. Using a low-flow cutoff for manure deposition by cattle reduces the possibility of unrealistic instantaneous violations, resulting in a more accurate descripition of the fecal coliform concentration in the stream. When the stream depth was less than 3 inches, direct deposition by cattle was multiplied by 0.001; at stream depth values greater than 3 inches, direct deposition was left unchanged. In modeling for the Mossy Creek TMDL, the simulated values using the 3-inch stage cutoff for direct deposition were closer in value to the observed data than the simulated values that had no cutoff (Benham *et al.*, 2004). To be completely accurate, the fecal coliform direct deposit loading removed as a result of the cutoff should be reapplied to the pasture area (cattle not wading and defecating in the stream will have to graze and defecate on the pasture). For Mossy Creek, the 'lost' fecal coliform numbers were so small compared to the loadings already being applied to the pasture that, were they added to the pasture loading in the ACCUM table, they would not change the number used in the ACCUM table given the significant figure limitation of the HSPF UCI file. Therefore, no manure was reapplied to the pasture areas.

For Mill Creek, the assumption was made that, like Mossy Creek, the amount of bacteria 'lost' due to the 3-inch cutoff would be insignificant compared to the amount of bacteria already represented in the ACCUM table for pasture. Therefore, there was no need to reapply this 'lost' load to pasture lands within the Mill Creek watershed.

Mill Creek Two period Water Quality Calibration

A significant, permanent drop in observed fecal coliform concentrations occurred in the middle of the observed data record. Mill Creek was, therefore, simulated as two sets of land use and management practices in order to capture the changes that had occurred in the watershed. Observed data were available for the period from December 1991 through 2003. The drop in observed fecal coliform concentrations occurred during calendar year 1998, when the one large dairy in the watershed ceased operation. Calibration was performed in a two period fashion. The first period of calibration ran from December 1991 through 1997 using one set of watershed characteristics. The observed data following the period of change ran from 1999 through 2003. This period was divided into two periods – from 1999 to 2000 – used for the second period of calibration, and from 2001 through 2003 to be used for validation with the same watershed characteristics used during the second period of calibration.

Output from the HSPF model was generated as an hourly timeseries and daily average time series of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by VADEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad \textbf{[5-2]}$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. The geometric mean was calculated on a calendar-month basis.

Figure 5-2 shows the daily average simulated fecal coliform concentrations and the observed data from the VADEQ sampling station for the first period of calibration. At the VADEQ sampling station the maximum observed concentration was the capped value of 8,000 cfu/100 mL and the overall maximum simulated concentration at this point was 119,000 cfu/100 mL. No volunteer data were collected during this period.

For the first period calibration, the geometric mean for the observed data was 932 cfu/100 mL (n=60), while the geometric mean for the simulated data at the Mill Creek outlet was 1,318 cfu/100 mL.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL was 75% for the observed data at the VADEQ station and 83% for the simulated data at the same location.

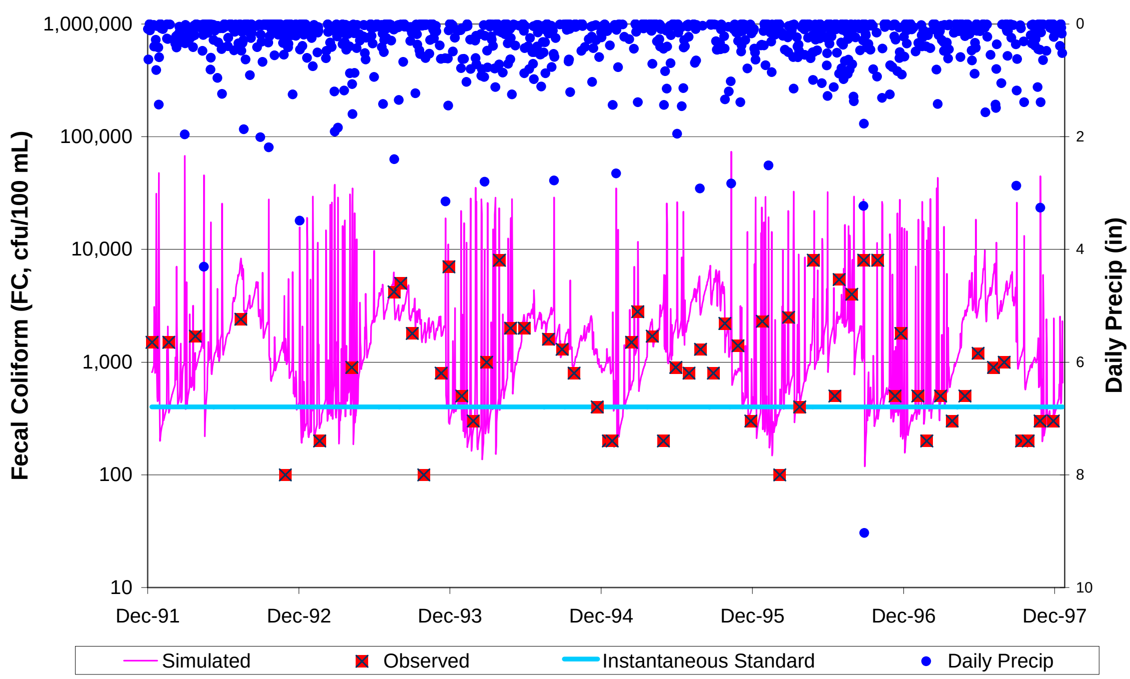

Figure 5-2. Observed and Simulated Fecal Coliform Concentrations for the First period of the Water Quality Calibration

During the second period calibration, many observed fecal coliform concentrations were at minimum detection levels (100 cfu/100 mL). Most nonpoint source models are usually better at estimating pollutants in higher ranges of values, so accuracy is constrained when modeling at low pollutant levels.

Figure 5-3 shows the daily average simulated fecal coliform concentrations and the observed data from the VADEQ and volunteer monitoring stations during the second period of calibration. The final calibrated water quality parameters are listed at the end of this section in Table 5-10.

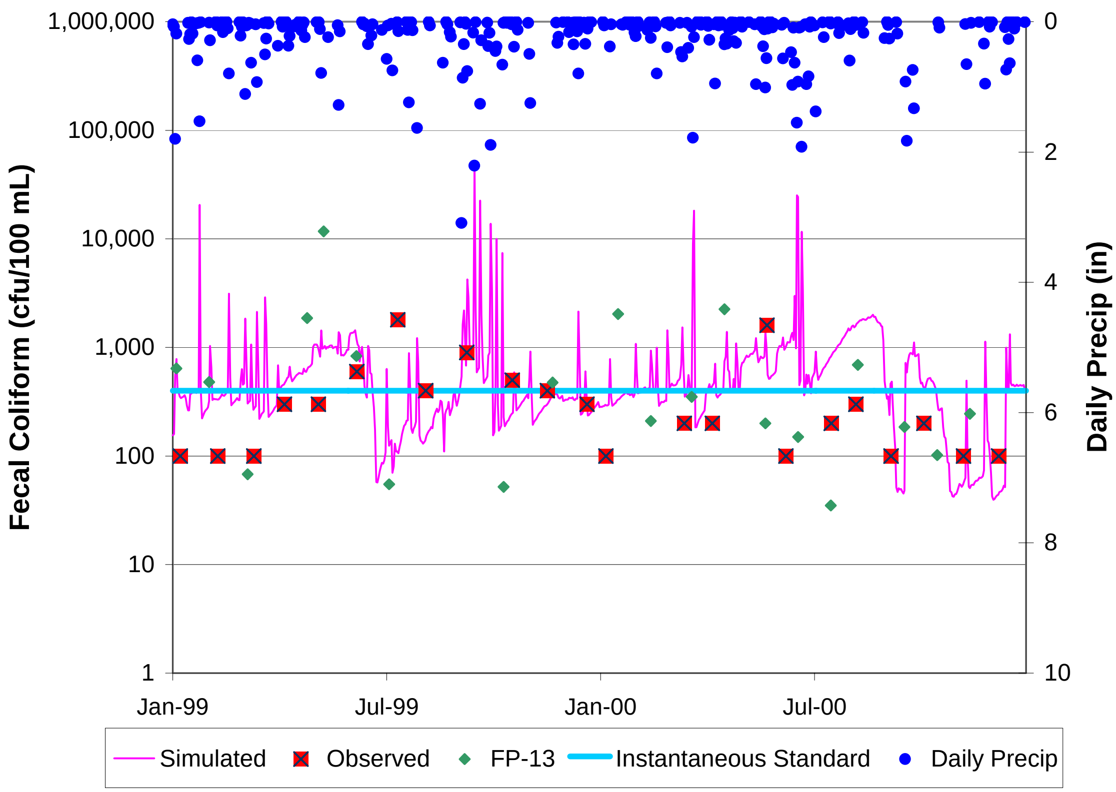

Figure 5-3. Observed and Simulated Fecal Coliform Concentrations for the Second Period of the Water Quality Calibration

In addition to the daily average simulated concentrations presented in the previous figures, a 'five-day window' was considered when performing the water quality calibration. Because the observed values are point-values and represent only an instant in time, it is not reasonable to expect the simulated daily arithmetic mean fecal coliform concentration to exactly match the observed value on a particular day. It is more reasonable to assume that at some point during a window of time surrounding the observed point, the model will simulate a concentration close to that observed. For this reason, we developed a 'five-day window' that considers the minimum and maximum simulated values from the 2 days before to the 2 days after an observed value is collected. We believe it is more reasonable to assume the observed value should fall within this window of simulated values than to assume it will match up with the daily average values presented in the previous figure. The five-day window of simulated values surrounding each observed VADEQ sample is presented graphically in Figure 5-4.

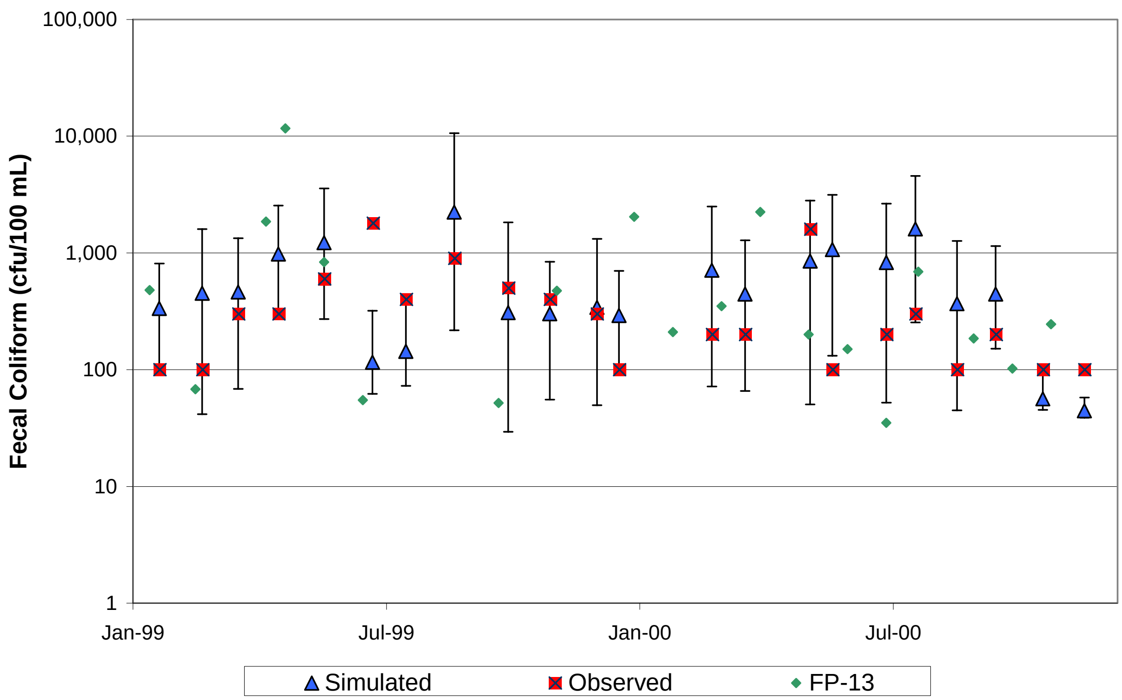

Figure 5-4. 'Five-Day Window' of Simulated Values Surrounding Each Observed VADEQ Sample in the Second period of the Water Quality Calibration.

At the VADEQ sampling station the maximum VADEQ-observed concentration was 1,800 cfu/100 mL, the maximum volunteer-observed concentration was 11,700 cfu/100 mL, and the overall maximum simulated concentration at this point was 8,580 cfu/100 mL.

Although differences occurred in the maximum concentrations, the geometric means were much similar. For the second period calibration, the geometric mean of the observed VADEQ data was 251 cfu/100 mL (n=23), the geometric mean of the volunteer data was 345 cfu/100 mL (n=20), and the geometric mean for the simulated data at the outlet of Mill Creek was 424 cfu/100 mL.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL was 30% for the VADEQ observed data (approximately 40% of that in the first period calibration), 45% for the volunteer data, and 50% for the simulated data.

Mill Creek Water Quality Validation

The water quality calibration was validated by comparing simulated output from the model of the watershed created for the second period of calibration with observed data from the 2001 through 2003 period. The observed and simulated fecal coliform concentrations for the validation period are shown in Figure 5-5. Figure 5-6 shows a plot of *E. coli* as translated from the simulated daily fecal coliform concentrations, together with observed data coinciding with the validation period.

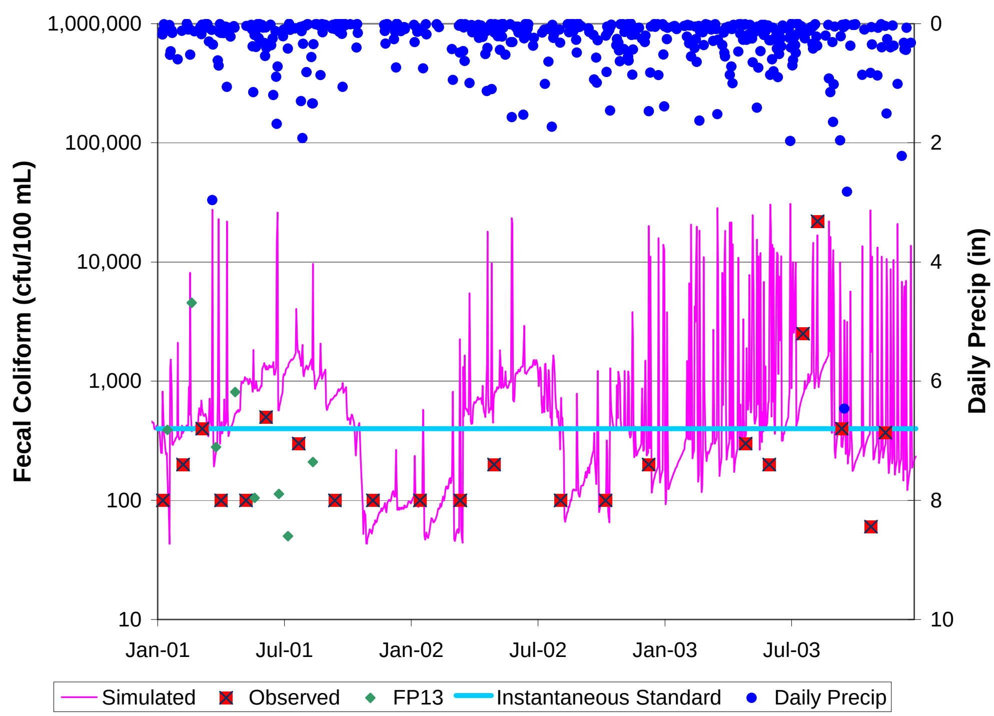

Figure 5-5. Observed and Simulated Fecal Coliform Concentrations for the Water Quality Validation Period.

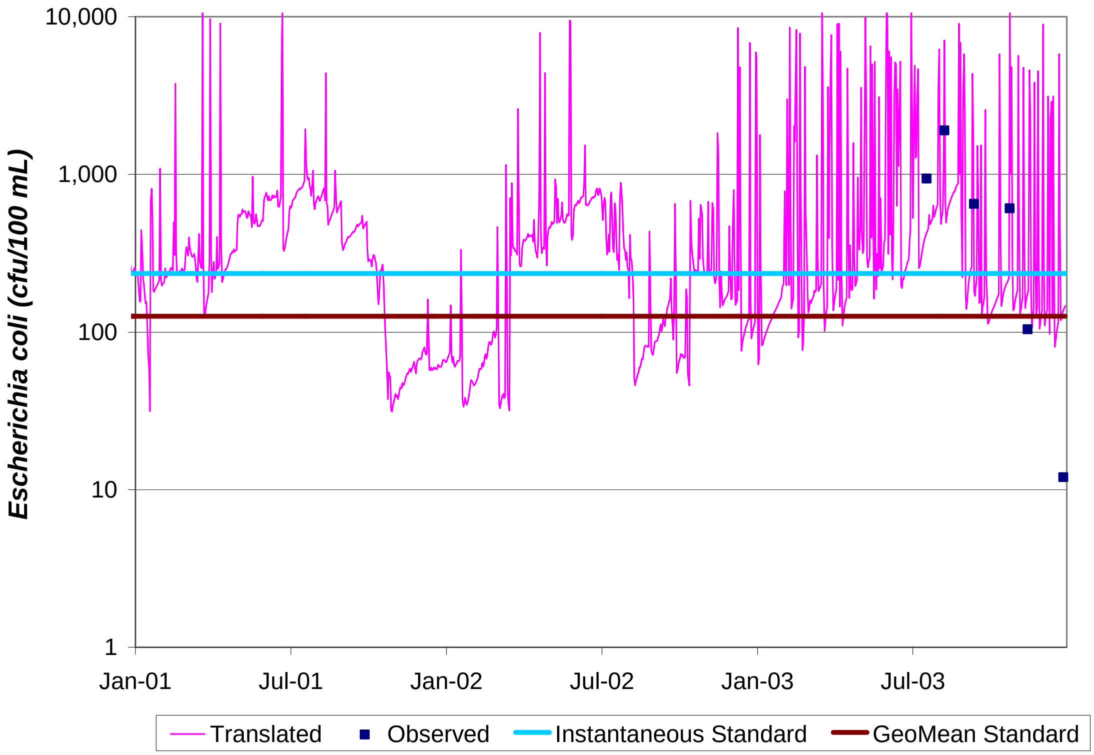

Figure 5-6. Observed and Translated *Escherichia coli* Concentrations for the Water Quality Validation Period.

At the VADEQ sampling station the maximum observed VADEQ concentration of fecal coliform bacteria was 22,000 cfu/100 mL, the maximum observed volunteer concentration was 4,550 cfu/100 mL, and the overall maximum simulated concentration at this point was 87,400 cfu/100 mL. For the analysis of samples from July 2003 through June 2004, VADEQ used an outside laboratory that used a higher maximum detection limit than applied to previous samples.

Although differences occurred in the maximum concentrations, the geometric means were much more similar. The geometric mean of the observed VADEQ data for the validation period was 217 cfu/100 mL (n=23), the geometric mean of the volunteer data was 290 cfu/100 mL (n=8), and the geometric mean of the simulated data at the outlet of Mill Creek was 483 cfu/100 mL.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL was 22% for the VADEQ observed data, 25% for the volunteer data, and 78% for the simulated data. For the existing conditions represented by the combined second period of calibration and the validation period, the violation rate of the instantaneous 400 cfu/100 mL criterion was 26% for the VADEQ observed data, 39% for the volunteer data, and 65% for the simulated data. The disparity between simulated and observed data might have been greatly reduced were flow data available for calibration of the hydrologic component. The greater simulated concentrations will instead serve as the basis for an implicit margin of safety in Mill Creek.

Mill Creek Calibration/Validation Discussion

The water quality calibration for Mill Creek resulted in parameter values that provided the best match for both the first calibration period and the second calibration period conditions. Many of the observed values during the second calibration period were at the minimum detection limit, a region of values for which simulation models were not specifically designed. The dramatic difference between the two calibration periods, however, is shown in Table 5-7 by the orders-of-magnitude decrease in load, especially from livestock land deposits, due to the removal of a 200-cow dairy and declining numbers of beef cattle between the first and second calibration periods. The second calibration period was also a period with below normal rainfall which resulted in even lower loads from livestock as well as other land deposited sources and is reflected in even further increased percentages of loads from the continuous direct deposit sources. During the validation period, rainfall was 50% above normal during 2003 increasing the total loads from most categories, and the percent contribution from land deposited bacteria whose transport to the stream is dependent on transport.

Table 5-7. Simulated contributions from major bacteria source categories for Mill Creek during calibration/validation.

Scenario	Livestock DD	Livestock Land	Wildlife DD	Wildlife Land	Septic Systems	Straight Pipes	Cats/ Dogs	Impervious	Interflow and Groundwater
First Calibration Period (1990 – 1997)									
Load (10^{10} cfu/yr)	300.3	6,555.3	24.2	30.1	21.1	43.0	30.6	0.2	1.6
Distribution	4.28%	93.53%	0.35%	0.43%	0.30%	0.61%	0.44%	0.00%	0.02%
Second Calibration Period (1999 – 2000)									
Load (10^{10} cfu/yr)	108.5	13.7	15.4	1.9	2.2	2.6	2.3	0.2	0.1
Distribution	73.92%	9.31%	10.47%	1.29%	1.49%	1.75%	1.55%	0.13%	0.10%
Validation Period (2001 – 2003)									
Load (10^{10} cfu/yr)	136.5	120.3	15.3	40.0	35.8	2.6	38.2	0.2	0.4
Distribution	36.33%	32.02%	4.06%	10.65%	9.53%	0.69%	10.15%	0.07%	0.11%

DD = direct deposit

The BST results for Mill Creek are shown in Table 5-8. The BST samples were taken on a monthly basis between July 2003 and June 2004. Conditions in the watershed when the BST samples were taken were similar to those during the validation period. For comparison with the simulated source contributions, the simulated categories for the validation period were lumped together to approximate the 4 BST categories, omitting contributions from impervious areas, interflow, and groundwater, which come from mixed sources.

Table 5-8. Bacterial source tracking results at the Mill Creek watershed outlet.

Source Contribution	% Livestock	% Wildlife	% Human	% Pets
BST Range	8-84	4-92	0-42	0-34
Concentration-Weighted BST Averages	52	25	16	7
Second Period Calibration Simulated Averages	65	14	11	10

Bacteria source tracking results are highly variable from sample to sample and should not be used as the sole basis for calibration of relative source contributions. The comparison in Table 5-8 shows an unusually high degree of similarity between the two sets of averages. Depending on whether a measurement is taken during a storm runoff event or in-between events, one might expect the livestock land deposits or livestock direct deposits to alternately dominate and fall within the range of the BST predictions at any given time. The combined contributions from straight pipes and septic systems fall within the observed range of data for human sources; the contributions from straight pipes would become more dominant during periods without rainfall. The wildlife values also fall within the observed range of data for wildlife sources, and again the direct deposit contributions would become more dominant during periods without rainfall.

The final parameter values used in the water quality calibration are listed in Table 5-10.

Table 5-9. Final hydrology calibrated parameters for Mill Creek.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	4-6	Soil properties	1
INFILT	Index to infiltration capacity	in/hr	0.15	Soil and cover conditions	
LSUR	Length of overland flow	feet	346-364[a]	Topography	1
SLSUR	Slope of overland flowplane	none	0.031-0.046[a]	Topography	1
KVARY	Groundwater recession variable	1/in	0.015	Calibrate	
AGWRC	Base groundwater recession	none	0.97-0.98	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	3	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.23	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0.02	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0.02	Marsh/wetland s ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	monthly[b]	Soil properties	3
NSUR	Mannings' n (roughness)	none	monthly	Land use, surface condition	1
INTFW	Interflow/surface runoff partition parameter	none	0.5, 0.75 - Forest	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.6	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	4

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

Table 5-10. Final water quality calibrated parameters for Mill Creek

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
QUAL-INPUT					
SQO	Initial storage of constituent	#/ac	$1x10^7$	Land use	
POTFW	Washoff potency factor	#/ton	0		
POTFS	Scour potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	monthly[b]	Land use	5
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP[b]	Land use	6
WSQOP	Wash-off rate	in/hr	2.3	Land use	
IOQC	Constituent conc. in interflow	#/ft3	2124	Land use	
PERLND					
AOQC	Constituent conc. in active groundwater	#/ft3	1416	Land use	
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	250	Topography	
SLSUR	Slope of overland flowplane	none	0.01	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.125	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
IQUAL					
SQO	Initial storage of constituent	#/ac	$1x10^6$		
POTFW	Washoff potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	$1x10^7$	Land use	
SQOLIM	Maximum accumulation of constituent	#	$3x10^7$	Land use	
WSQOP	Wash-off rate	in/hr	0.5	Land use	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		
GQUAL					
FSTDEC	First order decay rate of the constituent	1/day	1.1		
THFST	Temperature correction coeff. for FSTDEC		1.05		

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

CHAPTER 6: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

6.1. Background

The objective of the bacteria TMDL for Mill Creek was to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing fecal coliform and *E. coli* to Mill Creek. The sources can be separated into nonpoint and point (or direct) sources. The different sources incorporated into the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [6\text{-}1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was included by using a conservative calibration of water quality (bacteria) parameters. Creating a TMDL target based on a conservative calibration provides a slightly higher target that includes an allowance for uncertainty.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface or directly deposited in the stream; these reductions are presented in Table 6-2. In the model, decreasing these bacteria loads has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Table 6-3 and Table 6-4 are reductions in the amount of bacteria applied to the land surface or directly deposited in the stream that are needed to meet the applicable water quality criterion. These reductions are not intended to infer that agricultural producers should reduce their herd size or limit the use of manure as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

For Mill Creek, the same thirteen-year source allocation period (1990-2002) was used as in the bacteria TMDL for neighboring Hawksbill Creek.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values for each calendar month.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations. Equation 5-2 was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

6.2. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 6-1) shows that contributions from direct deposition by livestock manure in streams is the dominant source of *E. coli* in the stream (77.0%). Wildlife and household straight pipes are approximately equal representing 10.2% and 10.6%, respectively, of the total in-stream contributions, while the remaining portion comes from nonpoint source loading to the land surface, the Stanley sewage treatment plant's sanitary sewer overflows (SSO), and failing septic systems.

Table 6-1. Approximate contributions of different *E. coli* sources to the mean simulated *E. coli* concentration for Existing Conditions.

Source	*E. coli* Concentration by Source (cfu/100mL)		Approximate influence on Geometric Mean
	Daily Mean	Average Geometric Mean	
PLS Loads	478.1	21.2	7.7%
Livestock in streams	224.5	206.8	75.1%
Wildlife in Streams	31.9	28.4	10.3%
Straight Pipes	16.4	15.3	5.6%
ILS Loads	0.6	0.0	unknown[a]
SSOs	3.2	0.0	unknown[a]
Interflow and Groundwater	3.6	3.6	1.3%
All Sources[b]	758.3	383.4	

[a] While geometric means of ILS and SSO concentrations individually are zero, their contribution to in-stream concentrations is greater than zero as shown by daily means greater than 0. However, their relative influence on the geometric mean in combination with other sources is unknown.

[b] Because in-stream concentration is both flow and load dependent, the sum of individual concentrations will not equal the concentration when all sources are contributing.

The contribution of each of the sources detailed in Table 6-1 to the calendar-month geometric mean *E. coli* concentration is shown in Figure 6-1. As indicated in this figure, the calendar-month geometric mean value is dominated by direct deposits of cattle to streams that, by itself, would result in 64.7% of the violations of the calendar-month geometric mean goal of 126 cfu/100mL shown in Figure 6-1. Because contributions from upland areas only occur during storm runoff events, these influences are periodic rather than continuous, and have a smaller impact on the overall daily mean *E. coli* concentration. For the same reason, ILS contributions to the overall daily mean concentration are too small to be represented in Figure 6-1. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle tend to spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. Wildlife direct deposit and straight pipes also influence the mean concentration on a regular basis, though at a lower level. Since many sources contribute to the instream concentrations, contributions from several individual low-level sources may produce a cumulative load that results in bacteria concentration criteria violations. The influence of straight pipes to the overall mean concentration is significantly lower than the other sources.

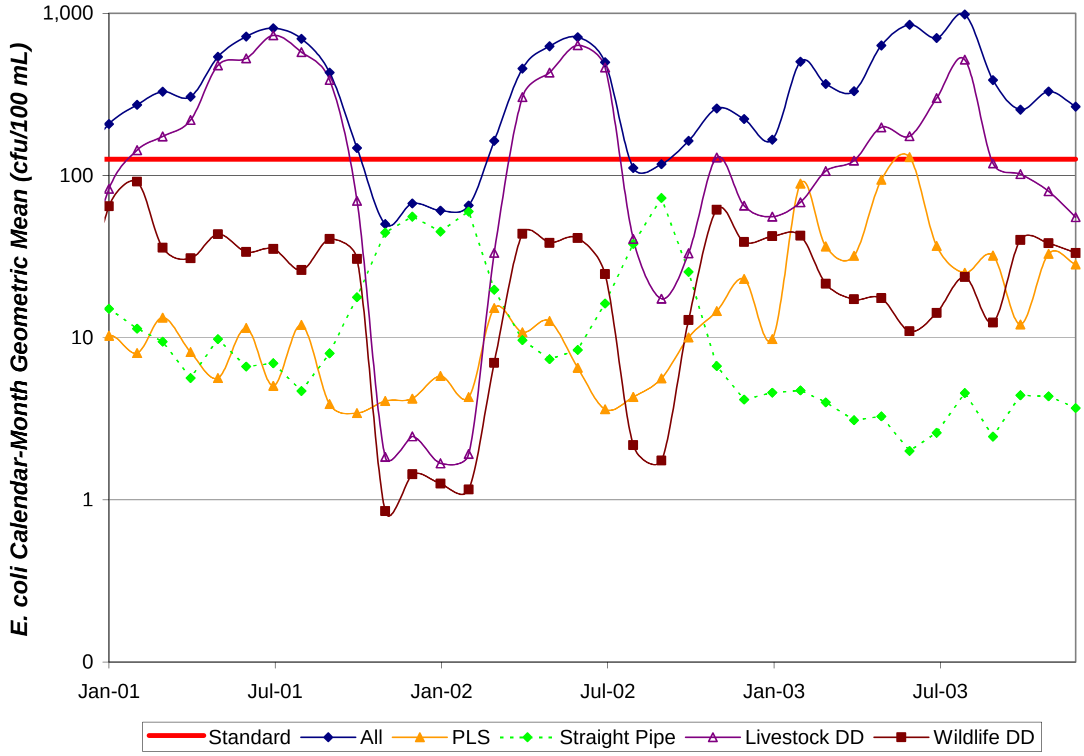

Figure 6-1. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for Existing Conditions during the validation period.

The daily average and calendar-month geometric mean *E. coli* concentrations for the thirteen year TMDL simulation period are shown in Figure 6-2.

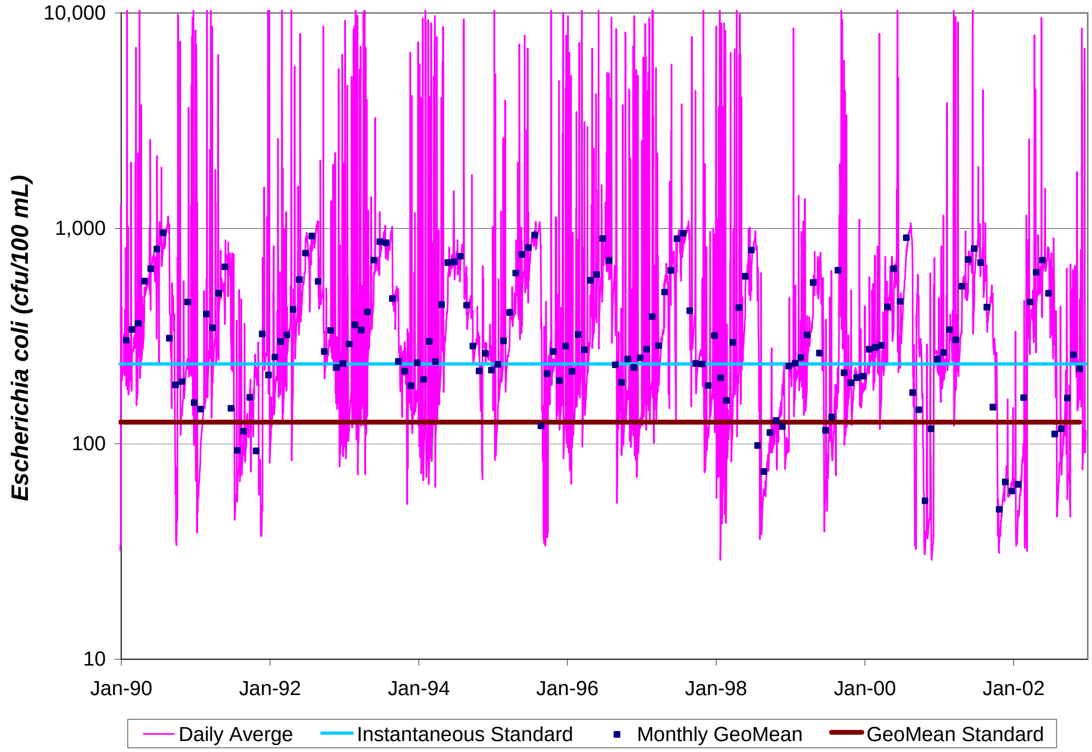

Figure 6-2. Daily average and calendar-month geometric mean *E. coli* concentrations for Existing Conditions, TMDL simulation period.

6.3. Future Conditions

Future conditions assumed the same watershed land use distribution and bacteria sources as used for Existing Conditions. The only difference from Existing Conditions was that poultry litter application rates were reduced to recommended rates for phosphorus-based manure applications, as detailed previously.

6.4. Allocation Scenarios

A variety of reduction scenarios were modeled to identify a TMDL scenario that would never exceed the *E. coli* TMDL concentration limits (a calendar-month geometric mean of 126 cfu/100mL and a single sample limit of 235 cfu/100mL). The scenarios and results are summarized in Table 6-2; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Because direct deposition of *E. coli* by cattle into streams comprised 77% of the mean daily *E. coli* concentration (Table 6-1) and because of the continuous nature of its contributions, it was obvious that the final TMDL allocation would require major reductions from direct deposits by livestock.

Table 6-2. Bacteria allocation scenarios for the Mill Creek watershed.

Scenario Number	% Violation of *E. coli* criterion		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%							
	Geomean	Single Sample	SSO	Straight Pipes	Failing Septic Systems	Livestock DD	Manure on Agriculture PLS	Residential PLS+ILS	Forest PLS	Wildlife DD
Existing Conditions	95%	60%	0	0	0	0	0	0	0	0
Future	89%	57%	0	0	0	0	0	0	0	0
1	89%	57%	100	0	0	0	0	0	0	0
2	83%	56%	100	100	0	0	0	0	0	0
3	83%	56%	100	100	100	0	0	0	0	0
4	39%	9.8%	100	100	100	84	50	50	0	0
5	33%	9.8%	100	100	100	80	80	80	0	0
6	0%	0.02%	100	100	100	100	100	100	0	0
7	0%	0%	100	100	100	100	100	100	40	0

- Stage 1 Scenarios
- TMDL Scenario

In all scenarios considered in Table 6-2, bacteria contributions from sanitary sewer overflows (SSOs) were eliminated because these contributions are covered under an existing out-of-the-watershed permit for the Stanley STP and are being addressed in conjunction with VADEQ. Two additional categories of bacteria contributions also addressed under existing regulations are household straight pipes and failing septic systems, which were eliminated in Scenarios 2 and 3, respectively, and in all succeeding scenarios. The reductions achieved from all of the currently regulated sources through Scenario 3, however, had little impact on reducing the overall percentage of bacteria violations. All following reduction scenarios will include reductions from the major influence on in-stream concentrations – livestock direct deposit (DD). Scenarios 4 and 5 represent alternative Stage 1 reduction scenarios with single standard criterion violation rates less than 10% (These will be discussed in detail in Chapter 7). Scenario 6 shows that violations of the single sample criterion cannot be eliminated even with 100% reductions from everything except background wildlife sources. The last scenario – Scenario 7 – was developed to eliminate all violations of both the calendar-month geometric mean and the single sample criteria and requires, in addition to all the previous reductions, a 40% reduction in the direct deposits in land deposited waste from wildlife, whose reductions are exempted under current state guidelines (for more detail, see Section 7.5.4). Because reductions have already been made to all other human-related sources of bacteria, Scenario 7 is the only option as a recommended TMDL scenario.

Loadings for existing conditions and the TMDL allocation scenario (Scenario 7) are presented for nonpoint sources by land use in Table 6-3 and for direct nonpoint sources in Table 6-4. It is clear that extreme reductions in loads, both from land surfaces and from sources directly depositing in the streams of Mill Creek are required to meet both the calendar-month geometric mean and single sample criteria for *E. coli*. Direct deposition by livestock in streams is the greatest influence on the *E. coli* concentration in-stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are minimal during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas becomes a major periodic influence on in-stream concentrations. Because these upland loadings are intermittent, they are a minor influence on concentrations that violate the calendar-month geometric mean standard, but they have a major influence on violations of the *E. coli* single sample criterion.

Table 6-3. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation Scenario 7.

Land use Category	Existing Conditions		Allocation Scenario 7	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	113	0.5%	0	100%
Pasture	20,257	96.8%	0	100%
Hay	284	1.4%	0	100%
Residential[a]	154	0.7%	0	100%
Forest	130	0.6%	78	40%
Total	20,937		78	-

[a] Includes loads applied to both High and Low Density Residential

Table 6-4. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation Scenario 7.

Source	Existing Condition		Allocation Scenario 7	
	Existing conditions load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
SSOs	0.8	1.2%	0	100%
Straight Pipes	0.7	1.0%	0	100%
Wildlife in Streams	7.1	10.0%	7.1	0%
Livestock in Streams	62.6	87.9%	0	100%
Total	71.3		7.1	-

E. coli concentrations were calculated by applying the VADEQ fecal coliform to *E. coli* translator to the HSPF predicted mean daily fecal coliform concentrations. The Scenario 7 fecal coliform loads presented in Table 6-3 and Table 6-4 will result in in-stream *E coli* concentrations that meet the applicable *E coli* water quality criteria. The concentrations for the calendar-month geometric mean and daily average *E. coli* values are shown in Figure 6-3 for the TMDL allocation (Scenario 7), along with the fresh water bacteria water quality criteria.

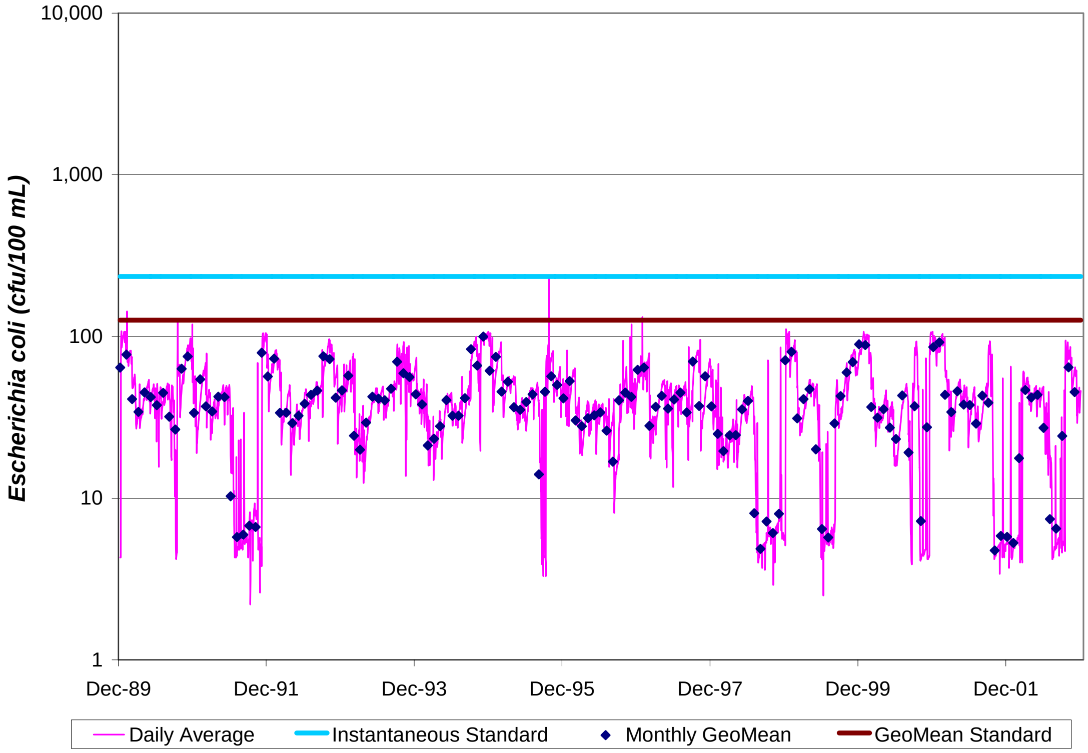

Figure 6-3. Calendar-month geometric mean and daily average *E. coli* concentrations for the TMDL allocation (Allocation Scenario 7).

6.5. Waste Load Allocation

There are no point source facilities in the watershed and, therefore, the WLA for Mill Creek is zero. Although sanitary sewer overflows (SSOs) have occurred in the past, they are not permitted. The town of Stanley has been under a State Water Control Board enforcement action since April 8, 2002. Under a consent order, the town is required, among other things, to initiate a program to reduce infiltration and inflow to the sewage collection system. These efforts will result in reduced incidence of sanitary sewer overflows in the Mill Creek watershed.

6.6. Summary

A TMDL for *E. coli* has been developed for Mill Creek. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.

2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL was developed.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and a conservative calibration of water quality (bacteria) parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Mill Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions. Violations of the instantaneous criterion were associated primarily with storm flows.

6. Both the flow regime and bacteria loading to Mill Creek are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 100% reduction in all categories of anthropogenic sources, as well as a 40% reduction in wildlife bacteria loadings to the land. The annual *E. coli* TMDL load for Mill Creek was calculated as the sum of allocated nonpoint source and direct nonpoint source loads in Tables 6-3 and 6-4. The remaining components of the TMDL defined in Eq. [6-1], are quantified in Table 6-5. No permitted point sources are located in the watershed, so the WLA load is zero. The MOS is implicit in the conservative calibration of the water quality parameter values. Therefore, the LA component load, in this watershed, is equal to the TMDL load.

Table 6-5. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Mill Creek bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS	TMDL
E. coli	0	8.51×10^{13}	Implicit	8.51×10^{13}

CHAPTER 7: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

7.1. TMDL Implementation Process

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairment on Mill Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

7.2. Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the greatest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice to address the bacteria TMDL is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers that reduce transport through surface runoff.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems and straight pipes should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement/installation program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other readily implemented BMPs for controlling urban wash-off from parking lots and roads may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

The iterative implementation of BMPs in a watershed using staged implementation has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;

4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

7.3. Stage 1 Scenario

The goal of the stage 1 scenario is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that the *E. coli* instantaneous criterion (235 cfu/100mL) is violated less than 10 percent of the time. The stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. Two alternative Stage 1 scenarios – Scenarios 4 and 5 – were presented in Table 6-2. The Stage 1 implementation scenarios were developed taking into consideration concerns expressed by the Local Steering Committee about stream fencing being the only alternative. Frequent flooding and fence maintenance were mentioned as potential concerns that might prevent local stakeholder participation in incentive programs that would offset only the installation cost of stream fencing. Both of the Stage 1 alternatives include reductions from other sources as well, but recognize that even the modest Stage 1 goal could not be achieved without as least some reductions from livestock direct deposit. Scenario 4 is the recommended Stage 1 scenario as the additional 4% reduction in direct livestock deposits would offset 30% fewer reductions from all upland land applied sources.

The scenario selected for Stage 1 implementation (Scenario 4, Table 6-2) requires elimination of all sanitary sewer overflows, straight-pipes, and failing septic systems, along with an 84% reduction in direct deposits by cattle to streams and 50% reductions from all anthropogenic sources of surface-deposited bacteria. No reduction in wildlife deposits to the stream is required. Fecal coliform loadings for the existing conditions and the Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 7-1 and for direct nonpoint sources in Table 7-2. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 4 fecal coliform loads are presented graphically in Figure 7-1.

Table 7-1. Annual nonpoint source fecal coliform reductions for Stage 1 TMDL implementation for Mill Creek watershed (Scenario 4).

Land use Category	Existing Conditions		Stage 1 Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	Nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	113	0.5%	56.5	50%
Pasture	20,257	96.8%	10,128.5	50%
Hay	284	1.4%	142.0	50%
Residential[a]	154	0.7%	77.0	50%
Forest	130	0.6%	130.0	0%
Total	20,937		10,534	-

[a] Includes loads applied to both High and Low Density Residential.

Table 7-2. Required direct nonpoint source fecal coliform reductions for Stage 1 Implementation (Scenario 4).

Source	Existing Condition		Allocation Scenario	
	Existing condition load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	Direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
SSOs	0.8	1.2%	0	100%
Straight Pipes	0.7	1.0%	0	100%
Wildlife in Streams	7.1	10.0%	7.1	0%
Livestock in Streams	62.6	87.9%	10.0	84%
Total	71.3		17.1	-

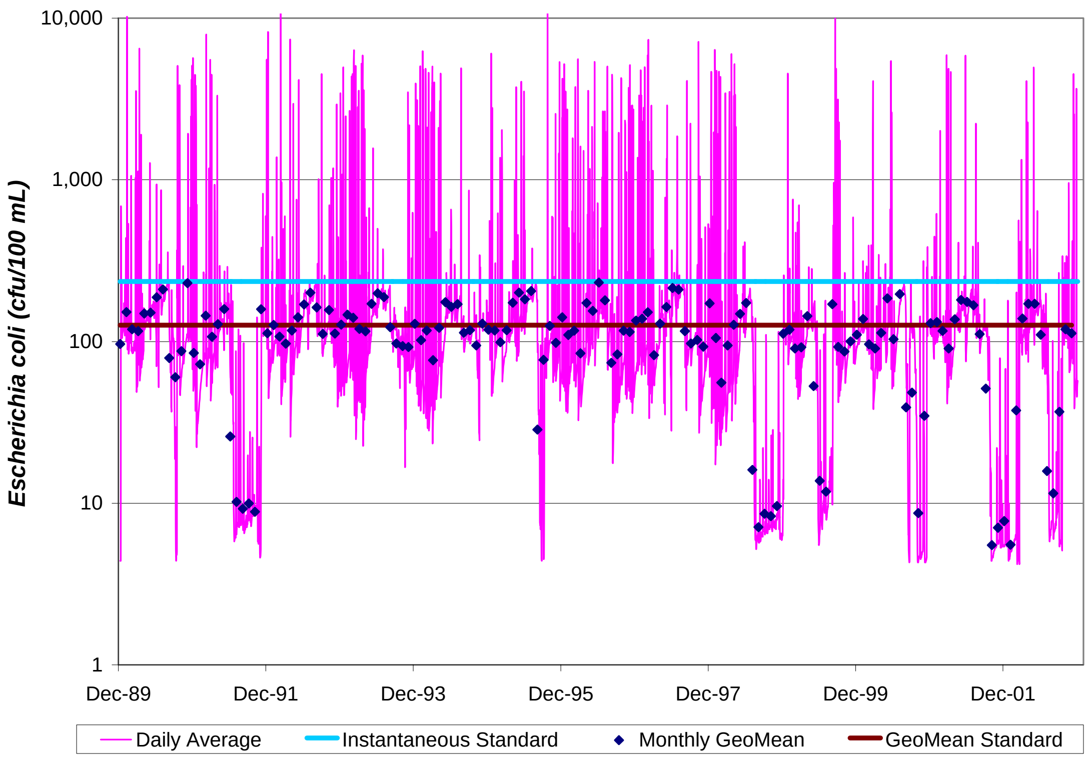

Figure 7-1. Stage 1 TMDL implementation scenario for Mill Creek.

7.4. Link to ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the Commonwealth of Virginia Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (VASNR, 1996). A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information can be found at the tributary strategy web site under http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

7.5. Reasonable Assurance for Implementation

7.5.1. Follow-up Monitoring

VADEQ will continue monitoring Mill Creek (1BMLC000.40) in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and also the effectiveness of TMDL implementation in attainment of water quality standards.

7.5.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

The Town of Stanley Sewage Treatment Plant (STP) is working with VADEQ to eliminate the sources of infiltration and other design limitations responsible for the periodic sanitary sewer overflows (SSOs) in compliance with its operating permit and with an enforcement action consent order.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

7.5.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

7.5.4. Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. As is the case for Mill Creek, these streams may not be able to attain standards without some reduction in wildlife load. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria were approved by the USEPA and became effective in February 2004. Additional information can be found at http://www.deq.virginia.gov/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 implementation scenario as presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 7.2 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedences attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

CHAPTER 8: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. On July 12, 2004, members of Virginia Tech's Center for TMDL and Watershed Studies in the Biological Systems Engineering Department, along with the regional VADEQ watershed coordinator and other watershed residents were invited by the Page County Water Quality Advisory Committee to take a watershed tour of Mill Creek in order to acquaint them with local features and concerns in the watershed. Later that afternoon, the first meeting of the Mill Creek Local Steering Committee was held at the Page County Court House in Luray, Virginia. At this meeting, initial population estimates were presented to the committee for feedback, together with a discussion of applicable land use and management characteristics of potential nonpoint sources of bacteria, as developed previously by the Local Steering Committee for neighboring Hawksbill Creek. Copies of the presentations for discussion were available at the meeting. Handouts and follow-up notes from this meeting were also posted on the Mill Creek (Page Co.) TMDL Forum at the Virginia Tech Center for TMDL and Watershed Studies' web site http://tmdl.net. Approximately 20 people participated in the watershed tour and committee meeting.

In addition, personnel from Virginia Tech's Center for TMDL and Watershed Studies contacted members of the Shenandoah Valley Soil and Water Conservation District (SWCD), Natural Resource Conservation Service (NRCS), Virginia Department of Game and Inland Fisheries, Virginia Cooperative Extension, and other watershed residents via telephone to acquire their input on various aspects of the watershed characteristics.

The first public meeting was held on October 20, 2004, also at the Page County Court House in Luray, to inform the stakeholders of the TMDL development process and to discuss the watershed and bacteria characterization data assembled by the Virginia Tech team to date. Copies of the presentation materials were available for public distribution at the meeting, and were also made available at the Virginia Tech web site. Approximately 27 people attended the meeting, and 14 people attended the follow-up steering committee meeting.

The third meeting of the Mill Creek Local Steering Committee was held on January 27, 2005 at the Page County Courthouse in Luray. A presentation was made by the Virginia Tech TMDL team regarding progress made with model calibration, refinements made to initial animal numbers and fecal production estimates, and preliminary allocation results from modeling of bacteria loads in the Mill Creek watershed. Approximately 20 people attended the meeting.

The final public meeting was held on March 2, 2005 at the Page County Court House in Luray to present the draft TMDL report and solicit comments from stakeholders. The final meeting was attended by 27 people. Copies of the presentation materials were distributed to the public at the meeting and were also available at the Virginia Tech web site. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA. The public comment period ended on April 2, 2005. One comment was received during the following 30-day comment period and was subsequently addressed by DEQ.

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APPENDIX A.
Glossary of Terms

Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot} x_n$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

APPENDIX B.
Sample Calculation of Cattle
(Sub Watershed MC-2)

Sample Calculation: Distribution of Cattle

(Sub watershed (MC-2) during January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the dairy herd is 200 milk cows, 50 dry cows, and 250 heifers.

1. During January, milk cows are confined 83% of the time (Table 4-4). Dry cows and heifers are confined 83% of the time.

Milk cows in confinement	=	200 * (83%)	=	166 (72)
Dry cows in confinement	=	50 * (83%)	=	41.5 (8)
Heifers in confinement	=	250 * (83%)	=	207.5 (38)

2. When not confined, dairy cows are on the pasture or in the stream.

Milk cows on pasture and in the stream	=	(200 - 166)	=	34
Dry cows on pasture and in the stream	=	(50 – 41.5)	=	9.5
Heifers on pasture and in the stream	=	(250-207.5)	=	42.5

3. Forty-six percent of the pasture acreage has stream access (Table 4-5) (recall dairy cows are assumed to graze only on Pasture 1). Hence dairy cattle with stream access are calculated as:

Milk cows on pastures with stream access	=	34 * (46%)	=	15.6
Dry cows on pastures with stream access	=	9.5 * (46%)	=	4.4
Heifers on pastures with stream access	=	42.5 * (46%)	=	19.6

4. Dairy cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 4-4) as:

Milk cows in and around streams	=	15.6 * (0.17/24)	=	0.11
Dry cows in and around streams	=	4.4 * (0.17/24)	=	0.03
Heifers in and around streams	=	19.6 * (0.17/24)	=	0.14

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 4.2)

Milk cows defecating in streams	=	0.11 * (30%)	=	0.03
Dry cows defecating in streams	=	0.03 * (30%)	=	0.01
Heifers defecating in streams	=	0.14 * (30%)	=	0.04

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).

Milk cows defecating on pasture	=	(34 - 0.03)	=	33.97
Dry cows defecating on pasture	=	(9.5 - 0.01)	=	9.49
Heifers defecating on pasture	=	(42.5 - 0.04)	=	42.46

APPENDIX C.
Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. A producer survey in Rockingham County showed that 15% of the dairy farms in the county had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.

3. The annual production of fecal coliform based on 'as-excreted' values was calculated for dairy manure.

4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 4-8.

APPENDIX D.
Weather Data Preparation

Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period using WDMUtil. Meteorological data created for the Hawksbill Creek TMDL for the period 1989 – 2002 was imported into WDMUtil as a starting point. Additional data was needed for all parameters for the year 2003 in order to have a longer period for calibrating to observed water quality data. Data for the entire 1989 – 2003 period was needed for average daily wind speed and average daily cloud cover. Locations and data periods from the stations used are listed in Table D-1. The Luray 5 E station (445096) was the primary station used to create the 2003 precipitation and temperature records. Missing periods of precipitation were calculated as the average of available data on the missing dates from 3 neighboring stations: Dale Enterprise (442208), Big Meadows (440720), and Edinburg (442663). The month of August and 11 other days were filled in this fashion. Missing temperature data at Luray was filled with daily values from Dale Enterprise. Current cloud cover data was not available at any station for the simulation period. Therefore, an artificial dataset was created based on a Dale Enterprise dataset developed by the Biological Systems Engineering Department at Virginia Tech for modeling various other TMDL watersheds in the Shenandoah Valley (Benham *et al.*, 2004). The cloud cover dataset for 1985-1997 was shifted to 1997-2003. The 1985-1997 dataset was truncated to 1989-1996, and then the 1989-1996 and 1997-2003 datasets were merged into one. Daily solar radiation, daily potential evapotranspiration, and daily pan evaporation were computed using WDMUtil. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU).

Table D.1. Meteorological data sources.

Station ID	Timestep	Data Type	Station Name	Start Date	End Date	Elevation (ft)
VA2208	Hourly	Precipitation	Dale Enterprise	9/1/1978	12/31/2003	1,400
WV6163	Hourly	Precipitation	Moorefield 1 SSE	5/1/1948	12/31/2000	890
VA8903	Hourly	Precipitation	Washington Dulles Intl	1/1/1984	12/28/2000	290
VA5096	Daily	Precipitation	Luray 5 E	8/1/1948	12/31/2003	1,400
VA5096	Daily	Min Temperature	Luray 5 E	8/1/1948	12/31/2003	1,400
VA5096	Daily	Max Temperature	Luray 5 E	8/1/1948	12/31/2003	1,400
VA0720	Daily	Precipitation	Big Meadows	1/1/2002	11/30/2003	3,540
VA2663	Daily	Precipitation	Edinburg	1/1/2002	12/31/2003	840
VA8903	Daily	Average Wind Speed	Washington Dulles Intl	1/1/1989	12/31/2003	290
VA8903	Daily	Dewpoint temperature	Washington Dulles Intl	1/1/1989	12/31/2003	290

APPENDIX E.
HSPF Parameters that Vary by Month or Land Use for Existing Conditions

Table E1. PWAT-PARM2 and PARM4 parameters that vary by land use for Mill Creek.

Land Use	LZSN (in)	LSUR (ft)	SLSUR	NSUR
Cropland	4	355	0.039	0.2
Pasture	4	349	0.044	0.2
Hay	4	349	0.044	0.2
Forest	6	346	0.046	0.2
Low Density Residential	6	351	0.042	0.2
High Density Residential	6	364	0.031	0.2
Commercial	6	364	0.031	0.2

Table E2. CEPSC (monthly interception storage capacity, inches) for Mill Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cropland	0.1	0.1	0.12	0.15	0.23	0.27	0.3	0.31	0.3	0.28	0.25	0.15
Pasture	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11
Hay	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11
Forest	0.13	0.13	0.15	0.19	0.29	0.34	0.37	0.38	0.37	0.35	0.31	0.19
Low Density Residential	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11
High Density Residential	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11
Commercial	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11
Loafing Lot	0.08	0.08	0.09	0.11	0.17	0.21	0.22	0.23	0.22	0.21	0.18	0.11

Table E3. UZSN (monthly upper zone storage, inches) for Mill Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cropland	0.3	0.35	0.3	0.45	0.56	0.57	0.45	0.67	0.64	0.6	0.6	0.5
Pasture	0.3	0.35	0.3	0.45	0.56	0.57	0.45	0.67	0.64	0.6	0.6	0.5
Hay	0.3	0.35	0.45	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.5
Forest	0.33	0.385	0.33	0.495	0.616	0.627	0.495	0.737	0.704	0.6	0.6	0.5
Low Density Residential	0.3	0.35	0.3	0.45	0.56	0.57	0.45	0.67	0.64	0.6	0.6	0.5
High Density Residential	0.3	0.35	0.3	0.45	0.56	0.57	0.45	0.67	0.64	0.6	0.6	0.5
Commercial	0.3	0.35	0.3	0.45	0.56	0.57	0.45	0.67	0.64	0.6	0.6	0.5
Loafing Lot	0.15	0.175	0.15	0.225	0.28	0.285	0.225	0.335	0.32	0.3	0.3	0.25

Table E4. LZETP (monthly lower zone evapotranspiration factor) for Mill Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cropland	0.2	0.2	0.25	0.3	0.5	0.55	0.6	0.6	0.5	0.6	0.5	0.4
Pasture	0.2	0.2	0.25	0.3	0.5	0.55	0.6	0.6	0.5	0.6	0.5	0.4
Hay	0.2	0.2	0.35	0.5	0.65	0.7	0.7	0.7	0.5	0.6	0.5	0.4
Forest	0.2	0.2	0.25	0.3	0.5	0.55	0.6	0.6	0.5	0.6	0.5	0.4
Low Density Residential	0.2	0.2	0.25	0.3	0.6	0.66	0.72	0.72	0.6	0.6	0.5	0.4
High Density Residential	0.2	0.2	0.25	0.3	0.6	0.66	0.72	0.72	0.6	0.6	0.5	0.4
Commercial	0.2	0.2	0.25	0.3	0.6	0.66	0.72	0.72	0.6	0.6	0.5	0.4
Loafing Lot	0.2	0.2	0.25	0.3	0.6	0.66	0.72	0.72	0.6	0.6	0.5	0.4

Table E5. NSUR (monthly Manning's "n" coefficient) for Mill Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cropland	0.1	0.1	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.1	0.1
Pasture	0.1	0.1	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.1	0.1
Hay	0.1	0.1	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.1	0.1
Forest	0.1	0.1	0.1	0.2	0.2	0.25	0.25	0.25	0.2	0.1	0.1	0.1
Low Density Residential	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1
High Density Residential	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1
Commercial	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1
Loafing Lot	0.1	0.1	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1

Table E5. ACQOP (monthly accumulation rate for fecal coliform) for Mill Creek

*** MC-1	January	February	March	April	May	June	July	August	September	October	November	December
101	7.50E+06	1.30E+08	3.30E+09	2.80E+09	5.60E+08	7.50E+06	7.50E+06	7.50E+06	7.50E+06	1.10E+09	1.10E+09	7.50E+06
115	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06	7.50E+06
108	1.10E+10	1.30E+10	1.40E+10	1.40E+10	1.40E+10	1.50E+10	1.50E+10	1.60E+10	1.60E+10	9.90E+09	1.00E+10	1.10E+10
129	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08
136	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
122	2.60E+08	2.60E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	2.60E+08	2.60E+08	2.60E+08
*** MC-2												
102	7.00E+06	2.30E+08	6.20E+09	5.30E+09	1.00E+09	7.00E+06	7.00E+06	7.00E+06	7.00E+06	2.00E+09	2.00E+09	7.00E+06
116	1.60E+07	5.90E+07	1.20E+09	1.00E+09	2.10E+08	2.20E+08	9.50E+07	9.50E+07	4.20E+08	4.10E+08	4.20E+08	1.60E+07
109	1.10E+10	1.30E+10	1.30E+10	1.40E+10	1.40E+10	1.40E+10	1.50E+10	1.50E+10	1.60E+10	9.60E+09	1.00E+10	1.10E+10
130	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09	3.10E+09
137	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11	1.60E+11
123	4.00E+08	4.00E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	4.00E+08	4.00E+08	4.00E+08
*** MC-3												
103	7.00E+06	2.00E+08	5.40E+09	4.70E+09	9.10E+08	7.00E+06	7.00E+06	7.00E+06	7.00E+06	1.70E+09	1.80E+09	7.00E+06
117	7.00E+06	5.50E+07	1.30E+09	1.10E+09	2.30E+08	2.30E+08	9.40E+07	9.40E+07	4.60E+08	4.40E+08	4.60E+08	7.00E+06
110	1.20E+10	1.40E+10	1.60E+10	1.60E+10	1.50E+10	1.50E+10	1.60E+10	1.60E+10	1.70E+10	1.10E+10	1.10E+10	1.10E+10
131	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09
138	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10	7.40E+10
124	2.00E+08	2.00E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	2.00E+08	2.00E+08	2.00E+08
*** MC-4												
104	6.90E+06	3.40E+08	9.10E+09	7.90E+09	1.50E+09	6.90E+06	6.90E+06	6.90E+06	6.90E+06	2.90E+09	3.00E+09	6.90E+06
118	6.90E+06	8.80E+07	2.20E+09	1.90E+09	3.80E+08	3.90E+08	1.50E+08	1.50E+08	7.70E+08	7.40E+08	7.70E+08	6.90E+06
111	1.10E+10	1.40E+10	1.90E+10	1.90E+10	1.50E+10	1.60E+10	1.60E+10	1.60E+10	1.80E+10	1.20E+10	1.20E+10	1.10E+10
132	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09
125	2.80E+08	2.80E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	1.50E+08	2.80E+08	2.80E+08	2.80E+08
*** MC-5												
119	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06
112	1.10E+10	1.30E+10	1.40E+10	1.40E+10	1.50E+10	1.50E+10	1.50E+10	1.60E+10	1.60E+10	9.90E+09	1.00E+10	1.10E+10
126	8.00E+08	8.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	8.00E+08	8.00E+08	8.00E+08

*** MC-6

106	7.20E+06	2.20E+08	5.80E+09	5.00E+09	9.80E+08	7.20E+06	7.20E+06	7.20E+06	7.20E+06	1.90E+09	1.90E+09	7.20E+06
120	9.80E+06	6.10E+07	1.40E+09	1.20E+09	2.40E+08	2.50E+08	1.00E+08	1.00E+08	5.00E+08	4.80E+08	5.00E+08	9.80E+06
113	1.10E+10	1.30E+10	1.70E+10	1.70E+10	1.50E+10	1.50E+10	1.50E+10	1.60E+10	1.70E+10	1.10E+10	1.10E+10	1.10E+10
134	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09
141	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10	4.60E+10
127	3.90E+08	3.90E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	2.20E+08	3.90E+08	3.90E+08	3.90E+08

*** MC-7

107	8.10E+06	1.30E+08	3.30E+09	2.80E+09	5.60E+08	8.10E+06	8.10E+06	8.10E+06	8.10E+06	1.10E+09	1.10E+09	8.10E+06
121	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06	8.10E+06
114	1.20E+10	1.40E+10	1.40E+10	1.40E+10	1.50E+10	1.50E+10	1.50E+10	1.60E+10	1.60E+10	1.00E+10	1.10E+10	1.10E+10
135	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08	6.70E+08
142	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10	2.30E+10
128	2.00E+08	2.00E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	2.00E+08	2.00E+08	2.00E+08

Table E6. SQOLIM Table for Mill Creek

*** MC-1	January	February	March	April	May	June	July	August	September	October	November	December
101	6.70E+07	1.20E+09	3.00E+10	2.60E+10	5.00E+09	6.70E+07	6.70E+07	6.70E+07	6.70E+07	9.50E+09	9.80E+09	6.70E+07
115	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07	6.70E+07
108	1.00E+11	1.20E+11	1.20E+11	1.30E+11	1.30E+11	1.30E+11	1.40E+11	1.40E+11	1.40E+11	8.90E+10	9.40E+10	9.80E+10
129	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09
136	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10	9.40E+10
122	2.30E+09	2.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	2.30E+09	2.30E+09	2.30E+09
*** MC-2												
102	6.30E+07	2.10E+09	5.60E+10	4.80E+10	9.30E+09	6.30E+07	6.30E+07	6.30E+07	6.30E+07	1.80E+10	1.80E+10	6.30E+07
116	1.40E+08	5.30E+08	1.10E+10	9.30E+09	1.90E+09	2.00E+09	8.50E+08	8.50E+08	3.80E+09	3.70E+09	3.80E+09	1.40E+08
109	1.00E+11	1.20E+11	1.20E+11	1.20E+11	1.30E+11	1.30E+11	1.30E+11	1.40E+11	1.40E+11	8.70E+10	9.10E+10	9.50E+10
130	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10	2.80E+10
137	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12	1.50E+12
123	3.60E+09	3.60E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	3.60E+09	3.60E+09	3.60E+09
*** MC-3												
103	6.30E+07	1.80E+09	4.90E+10	4.20E+10	8.20E+09	6.30E+07	6.30E+07	6.30E+07	6.30E+07	1.60E+10	1.60E+10	6.30E+07
117	6.30E+07	4.90E+08	1.20E+10	1.00E+10	2.00E+09	2.10E+09	8.50E+08	8.50E+08	4.10E+09	4.00E+09	4.10E+09	6.30E+07
110	1.00E+11	1.20E+11	1.40E+11	1.40E+11	1.30E+11	1.40E+11	1.40E+11	1.40E+11	1.50E+11	9.60E+10	1.00E+11	9.90E+10
131	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10	1.30E+10
138	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11
124	1.80E+09	1.80E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.80E+09	1.80E+09	1.80E+09
*** MC-4												
104	6.20E+07	3.10E+09	8.20E+10	7.10E+10	1.40E+10	6.20E+07	6.20E+07	6.20E+07	6.20E+07	2.60E+10	2.70E+10	6.20E+07
118	6.20E+07	7.90E+08	2.00E+10	1.70E+10	3.40E+09	3.50E+09	1.40E+09	1.40E+09	6.90E+09	6.70E+09	6.90E+09	6.20E+07
111	1.00E+11	1.20E+11	1.70E+11	1.70E+11	1.40E+11	1.40E+11	1.40E+11	1.40E+11	1.60E+11	1.10E+11	1.10E+11	9.80E+10
132	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10	3.20E+10
125	2.60E+09	2.60E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	1.40E+09	2.60E+09	2.60E+09	2.60E+09
*** MC-5												
119	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07
112	1.00E+11	1.20E+11	1.20E+11	1.30E+11	1.30E+11	1.30E+11	1.40E+11	1.40E+11	1.50E+11	8.90E+10	9.40E+10	9.90E+10
126	7.20E+09	7.20E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	3.60E+09	7.20E+09	7.20E+09	7.20E+09

*** MC-6

106	6.50E+07	2.00E+09	5.20E+10	4.50E+10	8.80E+09	6.50E+07	6.50E+07	6.50E+07	6.50E+07	1.70E+10	1.70E+10	6.50E+07
120	8.80E+07	5.50E+08	1.30E+10	1.10E+10	2.20E+09	2.30E+09	9.30E+08	9.30E+08	4.50E+09	4.30E+09	4.50E+09	8.80E+07
113	1.00E+11	1.20E+11	1.50E+11	1.50E+11	1.30E+11	1.40E+11	1.40E+11	1.40E+11	1.50E+11	9.80E+10	1.00E+11	9.80E+10
134	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10
141	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11	4.20E+11
127	3.50E+09	3.50E+09	1.90E+09	1.90E+09	1.90E+09	1.90E+09	1.90E+09	1.90E+09	1.90E+09	3.50E+09	3.50E+09	3.50E+09

*** MC-7

107	7.30E+07	1.20E+09	3.00E+10	2.60E+10	5.00E+09	7.30E+07	7.30E+07	7.30E+07	7.30E+07	9.50E+09	9.80E+09	7.30E+07
121	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07	7.30E+07
114	1.00E+11	1.20E+11	1.30E+11	1.30E+11	1.30E+11	1.40E+11	1.40E+11	1.40E+11	1.50E+11	9.10E+10	9.50E+10	1.00E+11
135	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09
142	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11
128	1.80E+09	1.80E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.00E+09	1.80E+09	1.80E+09	1.80E+09

APPENDIX F.
Fecal Coliform Loading in Sub-Watersheds

Table F-1. Monthly nonpoint fecal coliform loadings in sub-watershed MC-1.

Month	Fecal Coliform loadings (x10^{10} cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	1	4	13,397	193	124
Feb.	1	3	14,295	176	113
Mar.	1	4	16,132	110	124
Apr.	1	4	16,043	107	120
May.	1	4	17,010	110	124
Jun.	1	4	16,877	107	120
Jul.	1	4	17,865	110	124
Aug.	1	4	18,317	110	124
Sep.	1	4	18,245	107	120
Oct.	1	4	11,667	193	124
Nov.	1	4	11,849	187	120
Dec.	1	4	12,821	193	124
Total	10	43	184,518	1,703	1,463

[1]Includes Low Density Residential and High Density Residential Loads

Table F-2. Monthly nonpoint fecal coliform loadings in sub-watershed MC-2.

Month	Fecal Coliform loadings (x10^{10} cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	1	18	29,636	397	184
Feb.	1	16	31,625	362	168
Mar.	1	18	35,684	221	184
Apr.	1	17	35,483	214	178
May.	1	18	37,613	221	184
Jun.	1	17	37,308	214	178
Jul.	1	18	39,480	221	184
Aug.	1	18	40,477	221	184
Sep.	1	17	40,354	214	178
Oct.	1	18	25,801	397	184
Nov.	1	17	26,207	385	178
Dec.	1	18	28,359	397	184
Total	17	208	408,028	3,463	2,170

[1]Includes Low Density Residential and High Density Residential Loads

Table F-3. Monthly nonpoint fecal coliform loadings in sub-watershed MC-3.

Month	Fecal Coliform loadings (x10^{10} cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	3	8	31,702	167	269
Feb.	3	7	33,827	152	245
Mar.	3	8	38,188	94	269
Apr.	3	8	37,989	91	261
May.	3	8	40,306	94	269
Jun.	3	8	40,018	91	261
Jul.	3	8	42,393	94	269
Aug.	3	8	43,469	94	269
Sep.	3	8	43,216	91	261
Oct.	3	8	27,620	167	269
Nov.	3	8	28,046	162	261
Dec.	3	8	30,342	167	269
Total	36	94	437,116	1,465	3,172

[1]Includes Low Density Residential and High Density Residential Loads

Table F-4. Monthly nonpoint fecal coliform loadings in sub-watershed MC-4.

Month	Fecal Coliform loadings (x10^{10} cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	3	6	23,547	182	190
Feb.	2	5	25,128	166	173
Mar.	3	6	28,362	98	190
Apr.	2	6	28,210	94	184
May.	3	6	29,920	98	190
Jun.	2	6	29,696	94	184
Jul.	3	6	31,446	98	190
Aug.	3	6	32,242	98	190
Sep.	2	6	32,089	94	184
Oct.	3	6	20,508	182	190
Nov.	2	6	20,827	176	184
Dec.	3	6	22,535	182	190
Total	30	69	324,509	1,563	2,235

[1]Includes Low Density Residential and High Density Residential Loads

Table F-5. Monthly nonpoint fecal coliform loadings in sub-watershed MC-5.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	0	0	235	9	1
Feb.	0	0	251	9	1
Mar.	0	0	283	5	1
Apr.	0	0	281	5	1
May.	0	0	298	5	1
Jun.	0	0	295	5	1
Jul.	0	0	311	5	1
Aug.	0	0	319	5	1
Sep.	0	0	320	5	1
Oct.	0	0	204	9	1
Nov.	0	0	207	9	1
Dec.	0	0	224	9	1
Total	0	0	3,230	79	16

[1]Includes Low Density Residential and High Density Residential Loads

Table F-6. Monthly nonpoint fecal coliform loadings in sub-watershed MC-6.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	1	9	24,363	407	265
Feb.	1	8	25,999	371	242
Mar.	1	9	29,329	226	265
Apr.	1	8	29,158	219	257
May.	1	9	30,894	226	265
Jun.	1	8	30,630	219	257
Jul.	1	9	32,397	226	265
Aug.	1	9	33,213	226	265
Sep.	1	8	33,156	219	257
Oct.	1	9	21,201	407	265
Nov.	1	8	21,538	394	257
Dec.	1	9	23,311	407	265
Total	15	102	335,189	3,549	3,123

[1]Includes Low Density Residential and High Density Residential Loads

Table F-7. Monthly nonpoint fecal coliform loadings in sub-watershed MC-7.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)				
	Cropland	Hay	Pasture	Forest	Residential[1]
Jan.	1	6	19,122	136	276
Feb.	1	5	20,406	124	252
Mar.	1	6	23,032	74	276
Apr.	1	5	22,909	72	267
May.	1	6	24,297	74	276
Jun.	1	5	24,115	72	267
Jul.	1	6	25,536	74	276
Aug.	1	6	26,183	74	276
Sep.	1	5	26,059	72	267
Oct.	1	6	16,653	136	276
Nov.	1	5	16,913	131	267
Dec.	1	6	18,300	136	276
Total	12	65	263,524	1,175	3,254

[1]Includes Low Density Residential and High Density Residential Loads

APPENDIX G.
Required Reductions in Fecal Coliform Loads by Sub-Watershed – Allocation Scenario

Table G-1a. Required annual reductions in nonpoint sources in sub-watershed MC-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,020	0%	0	100%
Pasture	18,451,800	98%	4,267	100%
Hay	4,300	0%	0	100%
Forest	170,330	0.9%	170,330	0%
Residential	146,283	0.8%	0	100%
Total	18,773,722	100%	174,597	99%

Table G-1b. Required annual reductions in direct nonpoint sources in sub-watershed MC-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	60,802	85%	0	100%
Wildlife in Streams	9,150	13%	5,490	40%
Straight Pipes	1,773	2%	0	100%
Total	71,725	100%	5,490	92%

Table G-2a. Required annual reductions in nonpoint sources in sub-watershed MC-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,737	0%	0	100%
Pasture	40,821,497	99%	20,787	100%
Hay	2,080	0%	0	100%
Forest	346,283	0.8%	346,283	0%
Residential	216,959	0.5%	0	100%
Total	41,388,556	100%	367,070	99%

Table G-2b. Required annual reductions in direct nonpoint sources in sub-watershed MC-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	160,589	89%	0	100%
Wildlife in Streams	18,993	11%	11,396	40%
Straight Pipes	1,064	0.6%	0	100%
Total	180,647	100%	11,396	94%

Table G-3a. Required annual reductions in nonpoint sources in sub-watershed MC-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,551	0%	0	100%
Pasture	43,711,531	99%	9,368	100%
Hay	9,400	0%	0	100%
Forest	146,487	0.3%	146,487	0%
Residential	317,220	0.7%	0	100%
Total	44,188,189	100%	155,855	100%

Table G-3b. Required annual reductions in direct nonpoint sources in sub-watershed MC-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	80,251	88%	0	100%
Wildlife in Streams	8,161	9%	4,897	40%
Straight Pipes	2,306	3%	0	100%
Total	90,718	100%	4,897	95%

Table G-4a. Required annual reductions in nonpoint sources in sub-watershed MC-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,998	0%	0	100%
Pasture	32,456,886	99%	6,903	100%
Hay	6,900	0%	0	100%
Forest	156,263	0.5%	156,263	0%
Residential	223,533	0.7%	0	100%
Total	32,840,580	100%	163,166	100%

Table G-4b. Required annual reductions in direct nonpoint sources in sub-watershed MC-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	85,776	89%	0	100%
Wildlife in Streams	8,494	9%	5,097	40%
Straight Pipes	1,951	2%	0	100%
Total	96,222	100%	5,097	95%

Table G-5a. Required annual reductions in nonpoint sources in sub-watershed MC-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	0	0%	0	100%
Pasture	323,032	97%	20	100%
Hay	0	0%	0	100%
Forest	7,851	2%	7,851	0%
Residential	1,644	0.5%	0	100%
Total	332,527	100%	7,871	98%

Table G-5b. Required annual reductions in direct nonpoint sources in sub-watershed MC-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,738	86%	0	100%
Wildlife in Streams	436	14%	262	40%
Straight Pipes	0	0%	0	100%
Total	3,174	100%	262	92%

Table G-6a. Required annual reductions in nonpoint sources in sub-watershed MC-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,485	0%	0	100%
Pasture	33,518,947	98%	10,208	100%
Hay	10,200	0%	0	100%
Forest	354,875	1%	354,875	0%
Residential	312,289	0.9%	0	100%
Total	34,197,795	100%	365,083	99%

Table G-6b. Required annual reductions in direct nonpoint sources in sub-watershed MC-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	165,691	90%	0	100%
Wildlife in Streams	19,306	10%	11,583	40%
Straight Pipes	0	0%	0	100%
Total	184,997	100%	11,583	94%

Table G-7a. Required annual reductions in nonpoint sources in sub-watershed MC-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,191	0%	0	100%
Pasture	26,352,427	98%	6,500	100%
Hay	6,500	0%	0	100%
Forest	117,537	0.4%	117,537	0%
Residential	325,438	1%	0	100%
Total	26,803,092	100%	124,037	100%

Table G-7b. Required annual reductions in direct nonpoint sources in sub-watershed MC-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	70,113	82.5%	0	100%
Wildlife in Streams	6,462	7.6%	3,877	40%
Straight Pipes	0	0%	0	100%
SSOs	8,400	9.9%	0	100%
Total	84,975	100%	3,877	95%

APPENDIX H.
Simulated Stream Flow Chart for TMDL Allocation Period

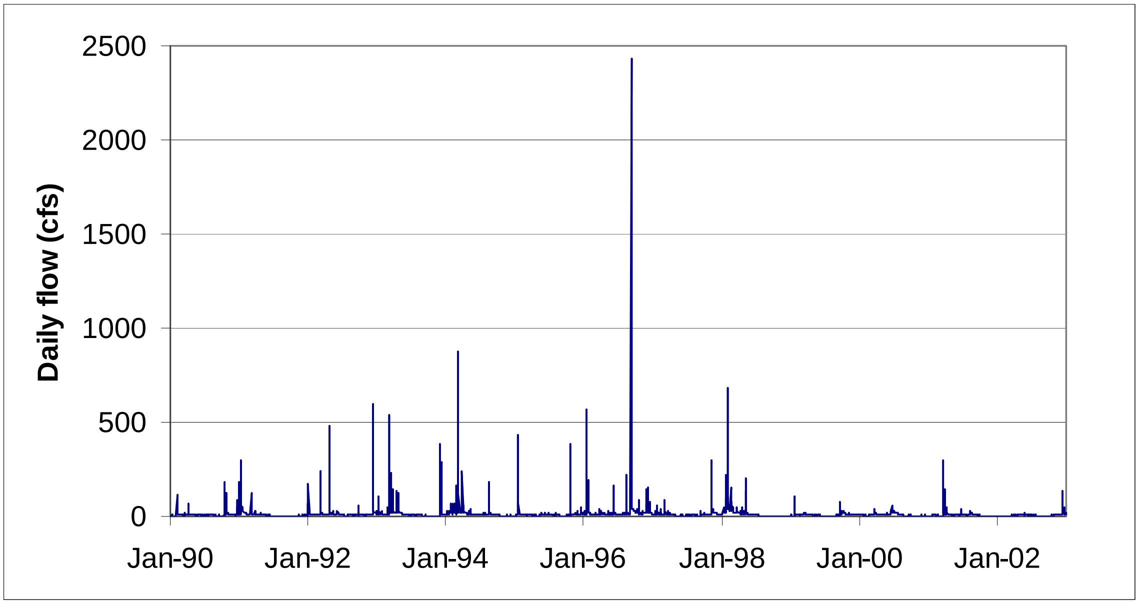

Figure H.1. Simulated Stream Flow for Mill Creek TMDL Allocation Period.

APPENDIX I.
Observed Bacteria Concentrations and Antecedent Rainfall

Table I.1. Observed fecal coliform concentrations and antecedent rainfall for the VADEQ station 1BMLC000.40 on Mill Creek.

Date	Fecal Coliform (cfu/100 mL)	Comment Code[a]	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
12/18/91	1,500		0.12
01/28/92	1,500		0.55
04/01/92	1,700		0.64
07/20/92	2,400		0.39
07/20/92			0.39
11/05/92	100		1.32
01/27/93	200		0.84
04/15/93	900		1.31
07/26/93	4,200		0.10
08/11/93	5,000		1.43
09/08/93	1,800		0.60
10/06/93	100		0.03
11/17/93	800		1.00
12/06/93	7,000		2.18
01/06/94	500		0.90
02/03/94	300		0.00
03/07/94	1,000		3.95
04/07/94	8,000	L	0.96
05/04/94	2,000		1.43
06/06/94	2,000		0.14
07/07/94			0.02
08/04/94	1,600		0.11
09/06/94	1,300		0.01
10/05/94	800		0.00
11/30/94	400		0.31
12/27/94	200		0.25
01/05/95	200		0.38
02/21/95	1,500		0.27
03/08/95	2,800		0.22
04/12/95	1,700		0.29
05/09/95	200		0.18
06/08/95	900		0.08
07/10/95	800		0.33
08/07/95	1,300		2.92
09/07/95	800		0.02
10/05/95	2,200		0.66
11/06/95	1,400		0.25
12/07/95	300		0.09
01/04/96	2,300		0.75
02/15/96	100		0.02
03/07/96	2,500		0.74

[a] “L” indicates maximum detection limit of the sample analysis.

Table I.2. (cont.) Observed fecal coliform concentrations and antecedent rainfall for the VADEQ station 1BMLC000.40 on Mill Creek.

Date	Fecal Coliform (cfu/100 mL)	Comment Code	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
04/03/96	400		1.84
05/06/96	8,000	L	1.77
06/27/96	500		1.17
07/08/96	5,400		1.39
08/07/96	4,000		0.96
09/05/96	8,000	L	3.53
10/09/96	8,000	L	1.09
11/20/96	500		0.23
12/04/96	1,800		1.17
01/08/97			0.06
01/14/97	500		0.49
02/05/97	200		0.40
03/10/97	500		0.33
04/07/97	300		0.00
05/08/97	500		0.00
06/09/97	1,200		0.62
07/16/97	900		0.00
08/11/97	1,000		0.01
09/22/97	200		0.10
10/08/97	200		0.00
11/06/97	300		2.10
12/08/97	300		0.09
01/08/98	8,000	L	1.26
02/11/98	600		0.25
03/09/98	3,700		0.18
04/06/98	600		0.78
05/12/98	5,600		1.53
06/09/98	500		0.07
07/08/98	1,900		0.41
08/04/98	1,700		0.13
09/08/98	1,800		0.39
10/13/98	500		0.99
11/12/98	100	U	0.27
12/07/98	600		0.00
01/07/99	100		2.06
02/08/99	100		0.06
03/11/99	100		0.72
04/06/99	300		0.45
05/05/99	300		0.01
06/07/99	600		0.00
07/12/99	1,800		0.79

[a] "L" indicates maximum detection limit of the sample analysis;
"U" indicates minimum detection limit of the sample analysis.

Table I.3. (cont.) Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for the VADEQ station 1BMLC000.40 on Mill Creek.

Date	Fecal Coliform (cfu/100 mL)	Comment Code	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
08/05/99	400		0.00
09/09/99	900		4.35
10/18/99	500		0.06
11/17/99	400		0.00
12/21/99	300		0.45
01/06/00	100		0.06
02/03/00			0.47
03/13/00	200		1.02
04/06/00	200		0.35
05/23/00	1,600		2.14
06/08/00	100	U	0.63
07/17/00	200		0.03
07/17/00			0.03
08/07/00	300		0.77
09/06/00	100	U	0.57
10/04/00	200		0.00
11/07/00	100	U	0.00
11/07/00			0.00
12/07/00	100		0.01
01/08/01	100	U	0.19
02/06/01	200	U	0.12
03/06/01	400		0.25
04/02/01	100	U	1.62
05/08/01	100		0.00
06/06/01	500		1.02
07/23/01	300		0.08
09/13/01	100		0.10
11/07/01	100		0.00
01/14/02	100		0.21
03/13/02	100		0.52
05/01/02	200		1.17
08/05/02	100	U	0.42
10/09/02	100		0.00
12/10/02	200		0.51
04/29/03	300		0.30
06/02/03	200		0.31

[a] “L” indicates maximum detection limit of the sample analysis;
“U” indicates minimum detection limit of the sample analysis.

Table I.2. Observed fecal coliform and *E. coli* concentrations in Bacteria Source Tracking samples and antecedent rainfall for the VADEQ station 1BMLC000.40 on Mill Creek.

Date	Fecal Coliform (cfu/100 mL)	*E coli* (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
07/21/03	2,500	940	0.04
08/11/03	22,000	1,900	0.64
09/15/03	400	650	2.17
10/27/03	60	610	0.83
11/17/03	370	104	0.44
12/29/03	40	12	0.32
01/12/04	80	166	
02/09/04	440	560	
03/22/04	60	42	
04/12/04	300	630	
05/10/04	130	330	
06/07/04	540	340	

Table I.3. Observed fecal coliform concentrations and antecedent rainfall for the volunteer monitoring stations around Mill Creek.

Date	Fecal coliform (cfu/100 mL)			Total Rainfall for Sampling Day and Preceding 5 Days
	FP-13	FP-13A	FP-13B	(inches)
09/24/94	675	645		1.30
10/22/94	500	720		0.02
11/06/94	445	260		0.41
12/10/94	140	695		0.74
01/21/95	90	155		0.89
02/11/95	154	675		0.00
03/25/95	64	70		0.16
04/08/95	440	320		0.00
05/06/95	640	7,580		0.62
06/03/95	480	440		0.04
07/08/95	68	195		0.09
08/26/95	1,860	1,235		0.00
09/09/95	11,700	107,000		0.00
10/07/95	835	5,850		2.00
11/04/95	55	570	141	0.26
12/09/95	690	1,290	3,580	0.26
02/10/96	52	500	75	0.09
03/23/96	475	785	185	1.80
05/18/96	2,035	1,190	20	0.60
06/15/96	210	640	DRY	1.94
07/20/96	350	510	410	1.46
08/17/96	2,250	ND	13,400	2.91
09/21/96	200	800	100	0.80
10/19/96	150	2,250	300	0.00
11/16/96	35	280	20	0.80
01/18/97	185		510	0.34
02/15/97	102		250	0.43
03/15/97	245		175	0.32
05/17/97	390		390	0.23
06/21/97	4,550		345	0.00
07/26/97	280		80	4.08
08/23/97	810		980	0.93
09/20/97	105		95	0.02
10/25/97	113		52	0.41
11/07/97	50		2	4.24
12/13/97	210		74	0.39

APPENDIX J.
CAFOs in the Mill Creek Watershed

Table J.1. Permitted Poultry CAFOs in Mill Creek.

Permit No.	Type	Pullets	Broiler-Breeders	Chicken	Turkey	Watershed
VPG260208B	Turkey hens	0	0	0	12,200	2
VPG260208L	Broilers/Turkeys	0	0	72,000	22,000	3
VPG260267	Turkey hens	0	0	0	45,600	3
VPG260558	Broilers	0	0	64,000	0	3
VPG26094	Broiler-Breeders	0	31,600	0	0	3
VPG260254	Broilers	0	0	37,700	0	4
VPG260362	Broilers	0	0	47,000	0	4
VPG260478	Broilers	0	0	72,000	0	4
VPG260547	Broilers	0	0	60,000	0	4
VPG260582	Broilers	0	0	138,000	0	4
VPG260653	Broilers	0	0	110,000	0	4
VPG260710	Broilers	0	0	62,000	0	4
VPG260741	Pullets (broilers)	51,000	0	0	0	4
VPG260169	Turkey hens	0	0	0	44,000	6
VPG260208L	Turkey hens	0	0	0	12,000	6
VPG260525	Broiler-Breeders	0	34,000	0	0	6
VPG260571	Broilers	0	0	19,000	0	6
VPG260617	Broilers	0	0	74,000	0	6
VPG260666	Broilers	0	0	46,000	0	6

APPENDIX K.
Calculation of Daily SSO Bacteria Loads for the Town of Stanley STP

Table K.1. Calculation of SSO Daily Bacteria Loads from the Town of Stanley STP.

Date	Luray Precipitation on Previous Days (inches)	Luray Precipitation on Day of Overflow (inches)	SSO Event Total Precipitation (inches)	Estimated Hrs of Overflow** (hrs)	Reported Volume of Overflow (gal)	Estimated Peak Flow (MGD)	Estimated Volume of Overflow (gal)	Station	Fraction of Daily Flow that is Overflowing	Calculated Daily FC Load / Day Due to Overflow	SSO Overflow Volume (gal/hr)	SSO Overflow Volume (ac-ft/hr)	SSO Overflow FC (cfu/hr)	Beg Hour	End Hour
02/24/92	0.186	0.325	0.511	4.5		0.3051	476	C	0.002	4.674E+09	105.7075	0.000324	1.039E+09	20	24
02/25/92			0.511	3		0.3051	317		0.001	3.118E+09	105.7075	0.000324	1.039E+09	0	3
04/21/92	0.559	0.198	0.757	8		0.3233	3,878	All 6	0.013	3.768E+10	484.7522	0.001488	4.710E+09	16	24
04/22/92		4.31	5.067	7		0.6420	49,880		0.143	4.209E+11	7125.738	0.021868	6.013E+10	0	7
07/23/92	0.554	0.137			1,500	0.3015	0	C	0.005	1.469E+10	375	0.001151	3.672E+09	20	24
07/24/92		0.14			2,000	0.3020	0		0.007	1.955E+10	500	0.001534	4.888E+09	0	4
10/23/92		0.199	0.199	2		0.3050	208	All 6	0.001	2.049E+09	104.1667	0.00032	1.024E+09	20	24
12/11/92	3.49	0.456	3.946	0.25		0.5591	1,350	C	0.004	1.322E+10	5398.466	0.016567	5.289E+10	20	21
12/13/92	0.124		4.07	0.5		0.5683	2,795	C	0.009	2.725E+10	5589.529	0.017154	5.450E+10	20	21
12/18/92	0.39		0.39	2		0.3050	208	C	0.001	2.049E+09	104.1667	0.00032	1.024E+09	20	24
03/04/93	1.2	1.91	3.11	12		0.4973	49,324	C	0.141	4.169E+11	4110.33	0.012614	3.474E+10	7	19
04/09/93		0.435	0.435	4.5	5,000	0.3050	0	All 6	0.016	4.840E+10	1111.111	0.00341	1.076E+10	16	21
04/16/93		1.07	1.07	1.5		0.3464	1,451	All 6	0.005	1.421E+10	967.0326	0.002968	9.471E+09	9	11
04/15/94					2,000	0.3020	0	C	0.007	1.955E+10	500	0.001534	4.888E+09	20	24
09/01/94					20,000	0.3200	0	C	0.063	1.845E+11	5000	0.015344	4.613E+10	20	24
05/30/95					20,000	0.3200	0	C	0.063	1.845E+11	5000	0.015344	4.613E+10	0	8
01/19/96		2.51	2.51	4		0.4529	12,743	All 6	0.041	1.203E+11	3185.831	0.009777	3.007E+10	20	24
01/20/96			2.51	10		0.4529	31,858		0.096	2.834E+11	3185.831	0.009777	2.834E+10	7	17
01/30/96	0.865		0.865	14		0.3313	9,116	C	0.029	8.707E+10	651.162	0.001998	6.219E+09	10	24
01/31/96			0.865	2		0.3313	1,302		0.004	1.276E+10	651.162	0.001998	6.380E+09	0	2
06/28/96				5		0.3050	521	C	0.002	5.117E+09	104.1667	0.00032	1.023E+09	16	21
09/06/96	5	9.03			374,000	0.6740	0	C	0.555	1.638E+12	93500	0.286942	4.096E+11	20	24
11/10/97	5.258	0.01			100,000	0.4000	0	4 out of 5	0.250	7.381E+11	25000	0.076722	1.845E+11	20	24
01/08/98	0.05	2.37		9.6	60,000	0.3600	0	4 out of 5	0.167	4.921E+11	6250	0.019181	5.126E+10	5	15
02/05/98	1.604	2.1	3.704	14		0.5412	70,358	4 out of 5	0.190	5.609E+11	5025.584	0.015423	4.006E+10	9	23
02/17/98		1.1	1.1	11		0.3486	11,146	4 out of 5	0.036	1.058E+11	1013.258	0.00311	9.614E+09	11	23
03/23/98					25,000	0.3250	0		0.077	2.271E+11	6250	0.019181	5.678E+10	18	22
07/20/01					72,000	0.3720	0		0.194	5.714E+11	18000	0.05524	1.429E+11	11	15
01/01/03				6		0.3050	625	C	0.002	6.138E+09	104.1667	0.00032	1.023E+09	15	21
02/22/03		1.63	1.63	6		0.3878	10,979	C	0.035	1.042E+11	1829.899	0.005616	1.737E+10	20	24
02/23/03		0.13	1.76	24		0.3974	48,725		0.140	4.125E+11	2030.207	0.00623	1.719E+10	0	24
02/24/03			1.76	18		0.3974	36,544		0.109	3.206E+11	2030.207	0.00623	1.781E+10	0	4
03/01/03	0.52	0.10	0.62	4		0.3128	1,064	C	0.004	1.043E+10	265.954	0.000816	2.608E+09	20	24
03/02/03		0.08	0.70	24		0.3187	9,341		0.030	8.915E+10	389.2206	0.001194	3.715E+09	0	24
03/03/03		0.01	0.71	4		0.3194	1,619		0.005	1.584E+10	404.6289	0.001242	3.961E+09	0	4
03/05/03		0.00		4		0.3050	417	C	0.001	4.095E+09	104.1667	0.00032	1.024E+09	20	24
03/06/03		0.02		4		0.3050	417		0.001	4.095E+09	104.1667	0.00032	1.024E+09	0	4
04/11/03	1.72	1.00	2.72	4		0.4685	14,038		0.045	1.320E+11	3509.405	0.01077	3.299E+10	2	19
07/03/03	0.34	1.97	2.31	4		0.4381	11,511	C	0.037	1.091E+11	2877.664	0.008831	2.727E+10	20	24
07/04/03		0.40	2.71	4		0.4679	13,994		0.045	1.316E+11	3498.62	0.010737	3.290E+10	0	4
09/19/03		6.46	6.46	18		0.7451	166,898	All 6	0.357	1.055E+12	9272.117	0.028455	5.863E+10	8	24
09/20/03		0.04	6.50	15		0.7480	140,006		0.318	9.394E+11	9333.751	0.028644	6.263E+10	0	16
09/23/03		2.82	2.82	11		0.4758	40,298	C and D	0.118	3.496E+11	3663.489	0.011243	3.178E+10	4	15
12/10/03		0.00		4		0.3050	417	C	0.001	4.095E+09	104.1667	0.00032	1.024E+09	20	24
12/11/03		2.22	2.22	24		0.4315	65,736		0.180	5.306E+11	2738.989	0.008406	2.211E+10	20	24
12/12/03		0.00	2.22	18		0.4315	49,302		0.141	4.167E+11	2738.989	0.008406	2.315E+10	0	18
09/08/04			7.00	5		0.7850	50,521		0.144	4.255E+11	10104.17	0.031009	8.510E+10	19	24
09/09/04		7.00	7.00	1		0.7850	10,104		0.033	9.620E+10	10104.17	0.031009	9.620E+10	0	1

Total rainfall for each SSO event is highlighted in **Bold** type.
** Where hours of overflow were not given, 4 hours will be used for the distribution.

Average Daily Treated Volume = 0.156 MGD
STP Capacity = 0.300 MGD

Overflow means daily flow > 0.30 MGD.
Estimated dilute wastewater FC = 500,000 cfu/100 mL

Assume constant FC load/day
= 0.156 MGD * 500,000 cfu/100 mL * 3.785×10^9 mL/MG
= 2.9523×10^{12} cfu/day

Estimated Peak Flow is either calculated as
= 0.3 MGD + overflow volume (gal)/10^6
or
is measured on a sliding scale based on Event Rainfall, where the event with the lowest recorded rainfall* is assumed to have an estimated peak of 0.305 MGD, ranging to the reported Hurricane Frances peak flow of 0.80 MGD for a rainfall total of 7.0".
or
= 0.305 MGD, if SSO precip total < 0.51

* 0.51" was used as the lowest rainfall to cause an overflow.

Col. J = (Overflow Volume - 0.30) / Overflow Volume

Therefore,
the calculated load/day (Col. J)
= 2.9523×10^{12} cfu/day * overflow fraction

Daily FC Load will be distributed over the number of hours of overflow reported.
Where hours were not reported, 4 hours will be used for beginning and ending dates, 24 hours for included dates.